Rees's Manufacturing Industry
(1819-20)

Volume Five

A selection from
The Cyclopaedia; or Universal Dictionary of Arts, Sciences and Literature
by
ABRAHAM REES

Edited by Neil Cossons

DAVID & CHARLES REPRINTS

first published serially 1802–20
Notes on the dating of various issues are given in the Introduction (see Volume 1)

Printed in Great Britain by
Redwood Press Limited, Trowbridge, Wiltshire,

Contents

List of Illustrations

CYCLOPÆDIA:

OR, A NEW

UNIVERSAL DICTIONARY

OF

ARTS and SCIENCES.

Slate

SLATE, *Argillaceous Schistus* and *Argillite* of Kirwan; *Clay-slate*, Jameson; *Thonschiefer*, Werner; *Schiste Argileux*, Fr.; in *Mineralogy* and *Geology*, one of the great rock-formations composing the crust of the globe, of which roof-slate is a well-known variety. The slaty or schistose structure is common to numerous rocks, which differ from each other, both in their geological position and constituent parts; hence we have a great variety of slate-rocks, amongst rocks which have been denominated primary, transition, and secondary. (See ROCKS.) The term slate appears to have a more appropriate meaning, when restricted to those rocks which, in their composition and structure, are most nearly allied to roof-slate or the clay-slate of Werner.

The most common colours of slate are a yellowish-grey, a greenish-grey, or a dark-blue or purple-grey: some varieties incline to a red, and others to a black-grey. Slate of the most perfect kind has a glistening lustre. It passes by gradation into mica-slate in the rocks called primary; and in rocks considered as secondary, it passes into slate-clay or shale.

The structure of slate-rocks *en masse* is tabular, the small structure laminar, the cleavage of the laminæ being parallel with the tables; hence slate has been represented by some geologists as most distinctly stratified; and the slaty cleavage is said to be always parallel with the strata; but this we believe to be a mistake, arising from confounding the divisions or joints of the tabular masses with the inclination of the beds. In the slate-quarries of Westmoreland and Cumberland, we have invariably observed the tables or divisions of the slate rise at a more elevated angle than the bed of which they form a part; and they are sometimes perpendicular, when the true dip of the bed is not more than forty degrees.

The slaty structure of the stone is the result of a process analogous to crystallization, by which the slate is divided into rhomboidal blocks or tables: between the bottom of one block and the top of another, there is frequently a seam of clay, which forms, what the workmen call, the foot of the slate. The slate will divide to this seam in a direction nearly at right angles with it; and sometimes between the upper and the lower block, there will be a thin horizontal stratum of slate occupying the place of the clay. This proves that the slate is not formed by mechanical stratification, and that the elevation of the tabular masses is unconnected with the elevation of the rock itself.

Slate-rocks vary in hardness, but they yield to the knife. They consist of an intimate intermixture, in various proportions, of siliceous earth, alumine, and iron; and sometimes contain a portion of lime, magnesia, manganese, and bitumen. Slate forms entire mountains, and mountain chains, and sometimes distinct beds, alternating with other rocks. It most frequently rests upon granite, gneiss, or mica-slate.

Slate-rocks are frequently intersected by veins of quartz, and by metallic veins of lead, cobalt, and silver: it also contains beds of copper pyrites, red copper-ore, copper-green, malachite, iron pyrites, magnetic pyrites, glance cobalt, grey cobalt-ore, arsenical pyrites, blende and galena. The tin-veins in Cornwall sometimes pass through the killas, which is a variety of slate-rock.

Various rocks frequently occur imbedded in slate, particularly whet-slate, or hone, chlorite-slate, talcous-slate, drawing-slate, and alum-slate. Beds of flinty slate occur in this rock, and alternate with as well as graduate into it. Flinty slate appears to be slate in which a large proportion of siliceous earth is combined, until it approaches nearly to the nature of chert or flint. Organic remains are occasionally found in slate, on which account it is not considered by many geologists as a primary rock, if indeed there be any to which that term is appropriate. The slate which contains organic remains has been called by the Germans *the newer clay-slate*, and *transition slate;* but remains of vegetables have been discovered in the slate of the Higher Alps in the vicinity of Mont Blanc, which may be supposed to have a better claim to the rank of primary than any other slate-rocks in Europe.

In a very large proportion of slate-rocks, the basis of the slate is intermixed with particles or fragments of other rocks; and when these are sufficiently large to be discerned without a lens, this kind of rock has received from the Germans the name of *grauwacke slate*. It is generally incumbent on the rocks denominated primary, and is supposed to be of more recent origin than the finer slate; but late observations have shewn that grauwacke is sometimes covered with granite and mica-slate. The killas of Cornwall appears, in many situations, to approach the nature of mica-slate, having a shining lustre, and a light grey colour, as if composed of an intimate intermixture of clay-slate with mica-slate. In Cornwall and Devonshire it occupies, in general, the same relative position with granite, in which mica-slate frequently occurs in other districts resting immediately upon it. The metallic veins which intersect these rocks are principally filled with ores of tin and copper, imbedded in a matrix of quartz; but it is observed, that the contents of the vein frequently vary as it passes through different rocks: if it contain tin-ore in the granite, it will change to copper-ores in the killas; and if tin be most

abundant in the killas, the vein will change its contents as it paſſes into the granite. Veins of granite are alſo obſerved to ſhoot up into the killas, which is a proof that this kind of ſlate-rock is at leaſt as ancient as the granite. This fact has given riſe to ſome controverſy among geologiſts, the diſciples of Werner contending that the granite in the ſlate or killas was not in veins, but formed ridges or inequalities riſing above the ſurface, which had been incloſed by ſubſequent depoſitions of the ſlate. For this explanation there can be no better reaſon given than its convenience in ſuiting a particular hypotheſis reſpecting the formation of theſe rocks. Among other facts, which might be cited to prove that the granite veins penetrate the ſlate, there is one deſcribed in the "Annals of Philoſophy," May 1814, which appears deciſive. It occurs in Touſchole, in Cornwall. "The ſlate or killas is of a greyiſh dark colour, rather hard, but breaks into large fragments in the direction of the ſtrata. The granite is of a fine grain, and the felſpar is of a light fleſh-colour, and contains but a ſmall portion of mica. At the junction, numerous veins of granite may be traced from the rock of granite into the ſlate. Some of theſe veins may be obſerved upwards of fifty yards, till they are loſt in the ſea; and in point of ſize, vary from a foot and a half to leſs than an inch. It may deſerve notice, that as the felſpar is of a fleſh-red colour, it is impoſſible for any obſerver to conſider them as quartz veins. One of theſe large veins is diſlocated, and heaved ſeveral yards by a croſs courſe. Another of theſe veins of granite, after proceeding vertically ſome diſtance, ſuddenly forms an angle, and continues in a direction nearly horizontal for ſeveral feet, with ſchiſtus, or ſlate, both above and below it. This appearance moſt completely deſtroys one of the theories ſuggeſted for the explanation of ſimilar veins at St. Michael's Mount; *viz.* that a ridge of projecting granite had been left, and ſlate depoſited afterwards on its ſides." It is, indeed, quite impoſſible to conceive that a narrow vein of granite ſhould ſhoot up into empty ſpace for a conſiderable diſtance, and then aſſume a zig-zag direction, unſupported by any ſolid ſubſtance on the ſides. The ſlate-rock muſt have exiſted when the vein was formed, and from its reſiſtance have given it the form above deſcribed. Slate is one of the moſt abundant rocks in alpine diſtricts, though that variety which ſplits into thin durable laminæ, forming good roof-ſlate, is far from being ſo common. The localities of common ſlate are ſo numerous in mountainous diſtricts, that it were uſeleſs to point them out. Roof-ſlate, the *ſchiſte ardoiſe* of the French, is found on the weſtern ſide of our iſland in the counties of Cornwall and Devon, in various parts of North Wales and Angleſea, on the north-weſt parts of Yorkſhire, near Ingleton, and in Swaledale, alſo in the counties of Cumberland and Weſtmoreland. It occurs in a low range of mountains at Chamwood foreſt, in Leiceſterſhire, near the centre of England. Several geologiſts have ſtated that ſlate is found in Derbyſhire, which is a miſtake, as no rock ſimilar to clay-ſlate or roof-ſlate occurs in that county. The inhabitants of that part of England make uſe of a micaceous ſand-ſtone for roofing, which they denominate ſlate. This ſtone is found in ſtrata among the other ſtrata accompanying coal. Of the quality of the different kinds of Engliſh roof-ſlate, we ſhall offer ſome obſervations at the concluſion of this article. Slate abounds in various parts of Scotland, and in the county of Wicklow, and other mountainous parts of Ireland. France poſſeſſes many valuable beds of roof-ſlate, near Laferriere in Normandy, and in the neighbourhood of Angers. The laſt is the moſt important, as furniſhing ſlate of the moſt perfect quality, and its extent and prodigious thickneſs make it regarded as inexhauſtible. It is further remarkable on account of the very ſingular and intereſting organic remains that occur between ſome of the laminæ of ſlate. It is, perhaps, one of the moſt valuable repoſitories of ſlate at preſent known.

This bed extends for a ſpace of two leagues, paſſing under the town of Angers, which is built, as well as covered, with the ſlate; thoſe blocks being employed in maſonry which are the leaſt diviſible. The quarries which are actually explored, are all in the ſame line from weſt to eaſt, as well as the ancient pits, the bed of the beſt roof-ſlate riſing to the ſurface in this direction. Immediately under the vegetable earth is found a brittle kind of ſlate, which, for four or five feet deep, ſplits into rhomboidal fragments.

A little lower is what is called the building-ſtone, which is a firm ſlate, but ſcarcely diviſible. This is employed in the conſtruction of houſes, after it has been ſufficiently hardened by expoſure to the air. At fourteen or fifteen feet from the ſurface is found the good ſlate, which has been quarried to the perpendicular depth of about three hundred feet; the remaining thickneſs being unknown.

As to the interior ſtructure of this great maſs of ſlate, it is divided by many veins or ſeams of calcareous ſpar and quartz, about two feet thick, by fifteen or ſixteen in height: theſe veins are parallel, and proceed regularly from weſt to eaſt, in a poſition riſing ſeventy degrees to the ſouth; they are interſected by other veins at intervals of a ſimilar kind, but whoſe riſe is ſeventy degrees north; ſo that when they meet the former, they either form rhombs, or half rhombs, which have been compared to the letter V, ſome being upright, and others reverſed.

All the layers, or laminæ, of the ſlate, have a direction ſimilar to thoſe of the veins of quartz, which riſe ſouth ſeventy degrees; and when interſected by veins that have an oppoſite inclination, the direction of the ſlaty laminæ is not changed. The whole maſs is thus divided into immenſe rhomboids, compoſed of plates all parallel among themſelves, and with two of the faces of the rhomboid.

The ſlate of Angers is extracted in blocks of a fixed ſize, which are divided into leaves for roofing-ſlate. It is betwixt theſe leaves that there are frequently found veſtiges of marine animals, and particularly pyritous impreſſions of *pous de mer* (the ſea-louſe, a ſmall univalve ſhell), alſo of ſmall chevittes (ſhrimps or prawns), and a ſpecies of crab, of which the body is about a foot in breadth, and fourteen or fifteen inches in length, the tail having nine or ten rings. The ſhrimps are ſometimes ſo numerous, that forty have been counted on a ſlate of a foot ſquare.

None of the above animals reſemble any known exiſting ſpecies. But the moſt remarkable circumſtance in theſe impreſſions, particularly in the large crabs, is, that though there be no ſign of the body having been cruſhed, yet it can ſcarcely be ſaid to have any thickneſs whatever. They rather reſemble engravings than figures in relievo, the convexity of theſe crabs above a thin leaf of ſlate not riſing more than the fourth, and ſometimes not more than the tenth part of a line; nor is it perceivable that the body of theſe crabs penetrates into the leaves of ſlate. What adds to the ſurpriſe, is the nearly vertical poſition in which theſe impreſſions are found in the mine.

A ſeries of theſe leaves of ſlate may be compared to a ſet of books placed upon ſhelves; and the impreſſions of crabs, and other marine animals, to engraved plates in the volumes: they do not, in fact, occupy more thickneſs. It is equally difficult to conceive how the bodies of theſe animals, though perfectly defined, could be reduced to a ſimple ſurface, with-

out thickneſs. Theſe ſlates alſo preſent beautiful dendritical pyrites, more than a foot in extent. The pyrites are ſometimes in ſmall grains, diſſeminated, like duſt, upon the ſurface of the ſlates, where may alſo be obſerved many little ſtars of ſelenite.

When the blocks of ſlate have been drawn from the quarry, if they are left expoſed to the ſun, or the open air, for ſome days, they loſe what is called the *quarry-water*, and then become hard and untractable, and can only be employed as building ſtone. Froſt produces a ſingular effect on theſe blocks: while frozen they may be broken with more eaſe than before; but if thawed rather quickly, they are no longer diviſible: yet this quality may be reſtored by expoſing them once more to the froſt; but if the operation be often repeated, it becomes impoſſible to reduce them to leaves.

Some ſmaller beds of ſlate are worked on the northern declivities of the Pyrenées; but we have no account of any ſlate-quarries on the ſouthern ſide, or in any part of Spain: yet it can ſcarcely be doubted that this rock exiſts in ſome of the mountainous parts of that kingdom.

Only one quarry of ſlate is ſaid to be opened in Italy; it is at Lavagna, in the ſtate of Genoa, and furniſhes ſlate of an excellent quality, and ſo impervious, that it ſerves to line the ciſterns in which olive oil is preſerved. The canton of Glaris, in Switzerland, is the only one in which roof-ſlate is procured. Roof-ſlate occurs in Saxony, and in various mountainous diſtricts in the north of Europe; it is found alſo on the continent of North America; and as it is only a modification of clay-ſlate, which is an abundant rock, it is probable that its localities are much more numerous than are at preſent known in alpine diſtricts in every part of the globe.

As this ſubſtance forms the moſt light, elegant, and durable covering for houſes, and is, of courſe, of conſiderable value; it is rather ſurpriſing that ſo much indifference prevails reſpecting the ſearch for it, in thoſe diſtricts where common ſlate, or *clay-ſlate*, abounds. We believe all the roof-ſlate quarries at preſent worked are thoſe which accident has diſcovered. This neglect is the more remarkable, when we conſider the great expence frequently incurred in ſearching for coal, a ſubſtance of much leſs value in proportion to the weight.

All the beſt beds of roof-ſlate with which we are acquainted, improve as they ſink deeper into the earth; and few, if any, are of a good quality near the ſurface, or are indeed ſuitable for the purpoſe of roofing. There cannot be a doubt that many beds of ſlate, which appear ſhattered and unfit for architectural uſe, would be found of a good quality a few yards under the ſurface; for the beſt ſlate, in many quarries, loſes its property of ſplitting into thin laminæ by expoſure to the air. Notwithſtanding the value of ſlate, few quarries are worked to a very great depth, or have ſubterranean galleries, like mines. The quarry or ſlate-mine at Rimagne, four leagues to the weſt of Charleville, on the Meuſe, in France, is an exception. The mouth of the mine is near the ſummit of a hill: the bed inclines forty degrees to the horizon: it is about ſixty feet in thickneſs, but its extent and depth are unknown. It has been purſued, by a principal gallery, to the depth of 400 feet; and they have driven many lateral galleries, which extend about 200 feet on the ſide of the main gallery, where 26 ladders are placed in ſucceſſion, for the paſſage of the workmen and the carriage of the ſlate. In this bed, which is 60 feet in thickneſs, there are only forty feet of good ſlate, the other being mixed with quartz. They cut the ſlate into blocks of about 200lbs., which they call *faix*: every workman, in his turn, carries them on his back to the very mouth of the pit, mounting the 26 ladders, or a part of them, according to the depth of the bed where he is working. When brought to day, theſe blocks are firſt ſplit into thick tables, which are called *repartons*. The workman holds the block between his legs, puts a chiſſel on the ſide, and divides it with a blow of a mallet. The *repartons* are divided in a ſimilar manner into roof-ſlates. Theſe operations muſt be performed ſoon after the blocks are drawn from the quarry; for if the ſtone has time to dry, it would no longer be poſſible to ſplit it. Some of the ſlate-galleries paſs under the river Meuſe.

There are few places in Great Britain where ſlate is worked as a mine under ground; moſt of the quarries are open to the day; and the covering of other rocks, or of coarſe ſlate, which requires removing, greatly increaſes the expence. There is one ſlate-quarry worked as a mine by penetrating the interior of the mountain at Place-Fell, on the head of the lake of Ullſwater, in Cumberland. Slate is alſo worked under ground on the weſtern ſide of Yorkſhire, adjoining Weſtmoreland. In many other ſituations it is probable that ſlate might be worked to advantage, in ſubterranean galleries, ſimilar to thoſe deſcribed in the quarries at Charleville; for as this mineral is generally of a better quality at a conſiderable depth, the expence of procuring it by mining would be much leſs than that of removing the load of upper rocks, and working it in open quarries, as at preſent; at leaſt the moſt valuable ſlate might be purſued to a far greater depth than is practicable in the common method in open quarries.

Slate, to be of a good quality for roofing, ſhould have the property of ſplitting into thin even laminæ: it ſhould reſiſt the abſorption of water; to prove which, it ſhould be kept ſome time immerſed in water, being weighed before and after the immerſion, wiping the ſurface dry; it is obvious, that the ſlate which gains the leaſt weight by this proceſs is the leaſt abſorbent. It ſhould reſiſt the proceſs of natural decompoſition by air and moiſture: this depends on its chemical compoſition and compactneſs, and is ſhewn by its reſiſting the proceſs of vegetation. That ſlate which is the moſt liable to decay, will be the ſooneſt covered with lichens and moſſes. The ſlate from Chamwood foreſt, in Leiceſterſhire, reſembles, in colour and appearance, the Weſtmoreland ſlate, but it will not ſplit ſo thin, nor would this be deſirable, for the vegetation which takes place upon it requires the roofs to be frequently ſcraped; this carries away a portion of the ſurface: a ſecond growth of moſſes produces a further wearing of the ſlate: hence a ſlate of a certain thickneſs from this part of England is not ſo durable as that from North Wales, Cornwall, or Weſtmoreland. This decay is probably owing to the greater quantity of alumine in its compoſition; it does not contain pyrites, nor have any organic remains been diſcovered in it.

Few ſlate-rocks have been accurately analyſed; a reddiſh-purple ſlate from North Wales contained, according to Kirwan, .38 ſilex, .26 alumine, .8 magneſia, .4 lime, and .14 parts iron; but as there is in this analyſis a loſs of 10 *per cent.*, it cannot be conſidered as very accurate. As the hardneſs of ſlate ariſes principally from the ſilex it contains, which is of all the earths the leaſt favourable to vegetation, thoſe ſlates which are the hardeſt when firſt taken from the quarry, and which have the leaſt ſpecific gravity, are to be preferred; for the increaſe of weight in ſlates is owing to the preſence of iron, either in pyrites, or a ſtate of oxyd. To the preſence of iron, many kinds of ſtone and ſlate alſo owe their tendency to decompoſition. The pyrites being decompoſed by moiſture, and the iron admitting

a ftill higher degree of oxygenation, the furface of the ftone fwells and peels off, or falls into an ochrey powder.

According to Dr. Watfon, (bifhop of Landaff,) the fpecific gravity of the Weftmoreland flate varies in different quarries, from 2797 to 2732 ounces the cubic foot. The effect of froft is very fenfible on tiled houfes, but is fcarcely felt on flated houfes; for good flate imbibes very little water. According to an experiment made by Dr. Watfon on Weftmoreland flate, compared with tile, in which two pieces of each, about 30 inches fquare, were immerfed in water 10 minutes, and then taken out and weighed as foon as they ceafed to drop; the tile had imbibed about $\frac{1}{7}$th of its weight of water, and the flate had not abforbed the $\frac{1}{200}$th part of its weight: indeed the wetting of the flate was merely fuperficial. When placed before the fire, in a quarter of an hour the flate was of the fame weight as it had been before it was put into the water; but the tile had only loft about 12 grains of its moifture, which was as near as could be expected to the quantity which had been fpread over its furface; for it was the amount gained by the flate, the furface of which was equal to that of the tile. The tile was left to dry fix days, in a room heated to fixty degrees, but did not lofe all the water it had imbibed till the end of that time.

The flate in Weftmoreland is blafted from the quarry in large maffes, and fplit with proper tools by the workmen. Though the fpecific gravity of Weftmoreland flate from different quarries is nearly the fame, yet all the forts are not capable of being fplit into an equal degree of thinnefs. Here alfo the quality varies with the depth of the quarry, that being the beft which is raifed from the greateft depth.

The grey-blue flate from Donyball, in Cornwall, weighs only 2512 ounces to the cubic foot, which is confiderably lighter than that of Weftmoreland. This flate is generally preferred to any other for its lightnefs, and enduring the weather; but Dr. Watfon is of opinion, that in durability it does not excel that of Weftmoreland. The Donyball flate is fplit into laminæ about one-eighth of an inch thick when it is applied to the covering of a roof; it then weighs rather more than 26 ounces to the fquare foot. The pale blue flate from Amblefide, in Weftmoreland, weighs about two ounces more in the fquare foot than the former. In many inftances, we believe flate of a thinner kind is ufed in feveral modern buildings to fave the expence of timber in the roof, where cheapnefs rather than durability is a principal object with the architect. According to an eftimate of Dr. Watfon, the relative weights of a covering of the following different materials, for forty-two fquare yards of roof, are as under:

	Cwt.
Copper	4
Fine flate	26
Lead -	27
Coarfe flate	36
Tile -	54

A ton of fine flate will cover a larger furface than a ton of lead; and where there is water-carriage, does not coft one-fourth of the price. Slate might, therefore, be ufed generally inftead of lead, with great advantage. Watfon's Chemical Effays, vol. iv.

The moft extenfive flate-quarries in Great Britain are the property of lord Penryn, near Bangor, in Caernarvonfhire. There is a rail-road formed from the quarries to the fea for the conveyance of the flate, which is of an excellent quality, and is fent to various parts of the world. The moft remarkable fituation where flate is procured in Cumberland, or perhaps in Great Britain, is Hourfton cragg, a lofty mountain near the lake of Buttermere, about 2000 feet above the level of the lake, and nearly perpendicular. On account of the difficulty of accefs, the workmen take their provifions for the week, and fleep in temporary huts on the fummit. During the winter months they are generally involved in clouds, and not unfrequently blocked up by the fnow. The flate is conveyed down a zigzag path cut in the rock on fledges, one man attending to prevent the acceleration of the defcent. When the flate is emptied at the bottom, the fledge is carried back on his fhoulders to the fummit.

There are confiderable flate-quarries near Ulverftone, in Lancafhire. A coarfe flate is got near Ingleton, in Yorkfhire, and alfo in the vicinity of Settle in that county. The Ingleton flate frequently contains cubical pyrites, and is fometimes covered with dendritical pyrites.

Alum-flate, *ampellite* of Haüy, is fometimes imbedded in clay-flate, but more frequently in ftratified fecondary rocks, and is not effentially different from fome of the coal-fhales. (See ALUM.) The alum-flate, or alum-fhale of Whitby, is of vaft and unknown thicknefs, forming the bafe of the Cleveland Hills in the North Riding of Yorkfhire, extending about thirty miles eaft and weft from Robinhood's bay, to Ginfborough, Stokefly, and Ofmotherly. On the fouth fide of the Cleveland Hills the alum-flate is principally covered by fand-ftone and marle. On the north-eaft, the alum-rock extends along the coaft, about thirty miles from Robinhood's bay to Huntcliff. The height of the alum-cliffs, which are perpendicular from the fea, varies from 100 to 140 yards. Whitby abbey ftands near an awful precipice of alum-flate or rock, which is undermined by every returning tide. At low water the alum-rock may be feen extending far to the eaft, forming a flat pavement, on which the obferver may walk fecure, treading at almoft every ftep on the organic remains of the inhabitants of a former world, which are abundantly diffeminated through the whole mafs beneath, and projecting from the fides of the black and frowning cliffs above. The alum-flate has been perforated near the fea to the depth of 130 yards, without difcovering the fubjacent rock, to which we may add the height of the cliffs above, which will make a total thicknefs exceeding 220 yards. The upper parts of the bed are found more productive of alum than the lower. From the quantity of pyrites contained in this rock, it fometimes takes fire fpontaneoufly, when a heap of it which has fallen from the cliffs becomes moiftened with fea-water.

The animal remains are fcattered through every part of the rock. They confift principally of numerous ammonites, nautilites, belemnites, foffile vertebræ (fuppofed to belong to the fhark), with bivalve fhells, foffile wood, and jet. Mr. Bakewell confiders the alum-fhale or flate, and the ftrata which cover it, as a peculiar local formation fubjacent to the roe-ftone, but above the coal-formation of Yorkfhire or Durham. The alum-flate is in fact a thin bed of indurated pyritous flate-clay, differing little, except in geological pofition and its organic remains, from fome of the coal-fhales.

The alum-flate of Whitby has a very dark grey colour, a flaty ftructure, and rather a filky luftre; it fplits, by expofure to the atmofphere, into very thin laminæ; it varies in hardnefs, but is all fofter than roof-flate. The particular advantage which the country near Whitby poffeffes for the manufacture of alum, is derived from the alum-flate rifing in precipitous cliffs, which afford facilities for working and burning the ftone. Though many of the coal-fhales might yield an equal quantity of alum, the difficulty of raifing

them to the ſurface would in moſt ſituations be too great to repay the expence. The alum-ſlate is piled in vaſt heaps and ſet fire to; a ſlow combuſtion is continued for ſeveral months, by the inflammable matter combined with the ſtone. The ſaline contents are extracted by ſolution, a ſmall quantity of potaſh is added, and the alum is cryſtallized by evaporation. (Bakewell's Introduction to Geology.) From the alum-rock of Yorkſhire, nearly all the alum of commerce in England is produced.

According to the analyſis of Klaproth, alum-ſlate contains

Sulphur - - - - - -	0.28
Carbon - - - - - -	1.96
Alumine - - - - - -	1.60
Silex - - - - - - -	4.00
Black oxyd of iron - - -	64
Sulphate of iron, lime, and potaſh, each	15
Water - - - - - - -	70

M. Klaproth remarks, that the ſulphur in the alum-ſlate which he analyſed was not united to the iron but to the carbon, in a manner at preſent unknown. In the alum-ſlate of Whitby, we believe the ſulphur is combined both with the iron and carbon.

Drawing-ſlate frequently accompanies alum-ſlate; it is much ſofter than common ſlate, and contains, like alum-ſlate, a conſiderable portion of carbon: its colour is a greyiſh-black: it is known by the property which it poſſeſſes of leaving a dark line when rubbed on paper. It is ſoft, and ſometimes rather unctuous: ſome varieties have a ſmall degree of luſtre. The fracture, in ſmall fragments, is ſcarcely ſlaty, and ſometimes approaches the conchoidal. Drawing-ſlate is eaſily cut with the knife. Under the blowpipe it turns white or yellow. It ſometimes effloreſces like alum-ſlate. According to Wiegleb, it contains

Silex - - - -	64
Alumine - - - -	21.25
Carbon - - - -	11
Oxyd of iron - - -	2.75
Water - - - -	7 50

Drawing-ſlate is employed by maſons, carpenters, &c. to mark with. When fine and pure, it is uſed by artiſts for deſigns. In France it is called *pierre d'Italie*, in England, *French chalk*. It is found in France, near Séer, in the department of l'Orne, and in the environs of Cherbourgh. It is found alſo in Spain and Italy.

Whet-ſlate, or hone, the *novaculite* of Kirwan, occurs imbedded in clay-ſlate: its moſt common colour is greeniſh-grey, inclining to yellow: it is much harder than common ſlate: its texture is fine-grained, nearly compact, and the fracture of the ſmall pieces ſplintery or conchoidal, reſembling flinty ſlate. Its ſpecific gravity is about 2.72. Whet-ſlate is tranſlucent on the edges; it does not efferveſce with acids, and it melts into a brown enamel under the blowpipe. From its green colour, and rather greaſy feel, it may be conſidered as intermediate between hard talcous-ſlate and clay-ſlate. Though it yields to the point of a knife, or even of a copper tool, it acts upon the flattened or round ſurfaces of metals, and is uſed for ſharpening and poliſhing the finer kinds of cutlery. It is of conſiderable value on account of this property, and was firſt brought from the Levant. We have no whet-ſlate of a fine quality in England. An inferior kind is procured from Chamwood foreſt, in Leiceſterſhire. It exiſts of a finer quality in the promontory of Howth, near Dublin. The common whet-ſlate of commerce is procured from Saxony.

Slate-*Spar*, *Schiefer-ſpath*, Werner, occurs in lime-ſtone beds, in mountains called primitive. Its colour is milk-white, or greeniſh and reddiſh-white, its luſtre ſhining and pearly. Slate-ſpar is tranſlucent and ſoft, its ſtructure coarſely lamellar, paſſing into ſlaty, and ſometimes curved or undulating: it is infuſible, and efferveſces with violence in acids.

Slate, in *Rural Economy*, a well-known, neat, convenient, and durable material, for the covering of the roofs of buildings. There are great varieties of this ſubſtance; and it likewiſe differs very greatly in its qualities and colours. In ſome places it is found in thick laminæ, or flakes; while in others it is thin and light. The colours are white, brown, and blue.

It is ſo durable, in ſome caſes, as to have been known to continue ſound and good for centuries. However, unleſs it ſhould be brought from a quarry of well reputed goodneſs, it is neceſſary to try its properties, which may be done by ſtriking the ſlate ſharply againſt a large ſtone, and if it produce a complete ſound, it is a mark of goodneſs; but if in hewing it does not ſhatter before the edge of the *ſett*, or inſtrument commonly uſed for that purpoſe, the criterion is deciſive. The goodneſs of ſlate may be farther eſtimated by its colour: the deep black-blue is apt to imbibe moiſture, but the lighter blue is always the leaſt penetrable: the touch alſo may be in ſome degree a guide, for a good firm ſtone feels ſomewhat hard and rough, whereas an open ſlate feels very ſmooth, and as it were greaſy. And another method of trying the goodneſs of ſlate, is to place the ſlate-ſtone lengthwiſe, and perpendicularly in a tub of water, about half a foot deep, care being taken that the upper or unimmerſed part of the ſlate be not accidentally wetted by the hand, or otherwiſe; let it remain in this ſtate twenty-four hours; if good and firm ſtone, it will not draw water more than half an inch above the ſurface of the water, and that perhaps at the edges only, thoſe parts having been a little looſened in the hewing; but a ſpongy defective ſtone will draw water to the very top. There is ſtill another mode, held to be infallible. Firſt, weigh two or three of the moſt ſuſpected ſlates, noting the weight; then immerge them in a veſſel of water twelve hours; take them out, and wipe them as clean as poſſible with a linen cloth; and if they weigh more than at firſt, it denotes that quality of ſlate which imbibes water: a drachm is allowable in a dozen pounds, and no more.

It may be noticed, that in laying of this material, a buſhel and a half of lime, and three buſhels of freſh-water ſand, will be ſufficient for a ſquare of work; but if it be pin plaſtered, it will take above as much more: but good ſlate, well laid and plaſtered to the pin, will lie an hundred years; and on good timber a much longer time. It has been common to lay the ſlates dry, or on moſs only, but they are much better when laid with plaſter. When they are to be plaſtered to the pin, then about the firſt quantity of lime and ſand will be ſufficient for the purpoſe, when well mixed and blended together, by properly working them.

Slates differ very much in thickneſs as well as colour, which ſuits them for different ſituations and purpoſes. A great deal of good ſlate of various kinds is raiſed in different parts of Wales, and much excellent blue and other coloured ſorts is procured from the northern parts of Lancaſhire, and other neighbouring places, as well as from different other counties throughout the kingdom. In ſome parts the ſlate is diſtributed into three kinds, as the beſt, the middling, and the waſte or common ſort. See Quarry.

Slate-*Axe*, provincially a mattock with a ſhort axe-end, uſed in ſlating, &c.

Slich

SLICH, in *Metallurgy*, the ore of any metal, particularly of gold, when it has been pounded, and prepared for farther working.

The manner of preparing the flich at Cremnitz, in Hungary, is this: they lay a foundation of wood three yards deep, upon this they place the ore, and over this there are four-and-twenty beams, armed at their bottoms with iron; thefe, by a continual motion, beat and grind the ore, till they reduce it to powder: during all this operation, the ore is covered with water. There are four wheels ufed to move thefe beams, each wheel moving fix; and the water, as it runs off, carrying fome of the metalline particles with it, is received into feveral bafons, one placed behind another; and finally, after having paffed through them all, and depofited fome fediment in each, it is let off into a very large pit, of almoft half an acre of ground; in this it is fuffered to ftand fo long, as to depofit all its fediment, of whatever kind, and after this it is let out. This work is carried on day and night, and the ore taken away, and replaced by more, as often as occafion requires. That ore which lies next the beams, where it was pounded, is always the cleaneft or richeft.

When the flich is wafhed as much as they can, a hundred weight of it ufually contains about an ounce, or perhaps but half an ounce of metal; which is not all gold, for there is always a mixture of gold and filver, but the gold is in the largeft quantity, and ufually is two-thirds of the mixture: they then put the flich into a furnace with fome lime-ftone, and flaken, or the fcoria of former meltings, and run them together. The firft melting produces a fubftance, called *lech;* this lech they burn with charcoal, to make it lighter, to open its body, and render it porous, after which it is called *roft;* to this roft they add fand in fuch quantity as they find neceffary, and then melt it over again.

They have at Cremnitz many other ways of reducing gold out of its ore, but particularly one, in which they employ no lead during the whole operation; whereas, in general, lead is always neceffary, after the before-mentioned proceffes. See Gold.

Smeaton

SMEATON, JOHN, an eminent civil engineer, was born on the 28th of May, 1724, at Austhorpe, near Leeds. The strength of his understanding, and the originality of his genius, appeared at an early age; his playthings were not the playthings of children, but the tools which men employ; and when he was a mere child, he appeared to take greater pleasure in seeing the operations of workmen, and asking them questions, than in any thing else. Before he was six years old, he was once discovered at the top of his father's barn, fixing up what he called a wind-mill of his own construction; and at another time, while he was about the same age, he attended some men fixing a pump, and observing them cut off a piece of the bored part, he procured it, and actually made a pump, with which he raised water. When he was under fifteen years of age, he made an engine for turning, and worked several things in ivory and wood, which he presented to his friends. He made all his own tools for working in wood and metals, and he constructed a lathe. by which he cut a perpetual screw in brass, a thing but little known, and which was the invention of Mr. Henry Hindley of York, with whom Mr. Smeaton became acquainted, and indeed extremely intimate. Mr. Smeaton, by the time that he was eighteen years of age, acquired, by the strength of his genius and indefatigable industry, an extensive set of tools, and the art of working in most mechanical trades, without the assistance of a master. A part of every day was usually occupied in forming some ingenious piece of mechanism. His father was an attorney, and being desirous to bring up his son to the same profession, he brought him up to London with him in 1742, and attended the courts in Westminster-Hall; but after some time, finding that the law was not suited to his disposition, he wrote a strong memorial to his father on the subject, who immediately desired the young man to follow the bent of his inclination. In 1751 he began a course of experiments to try a machine of his own invention to measure a ship's way at sea, and also made two voyages, in company with Dr. Knight, to try the effect of it, and also for the purpose of making experiments on a compass of his own construction, which was rendered magnetical by Dr. Knight's artificial magnets. In 1753 he was elected a fellow of the Royal Society; and the number of papers which he published in their Transactions, will shew how highly he deserved the honour of being enrolled a member of that useful and important body. In 1759 he received from the council of the Royal Society, by an unanimous vote, their gold medal for his paper, entitled "An experimental Inquiry concerning the natural Powers of Water and Wind to turn Mills and other Machines, depending on a circular Motion." The paper was the result of experiments made on working models in the years 1752 and 1753, though not communicated to the society till 1759; and in the interval he had opportunities of carrying into effect several of his inventions and theories, which rendered his paper of much more real value to the society and the public at large. In 1755, the EDDYSTONE *Light-house* was burnt down (see the article), and Mr. Smeaton being recommended to the proprietors of that building as an engineer in every way calculated to rebuild it, he undertook the work, which was completed in 1759, much to the satisfaction of the parties concerned. Still he was not fully employed as a civil engineer, for in the

year 1764, while he was in Yorkſhire, he offered himſelf as a candidate for the office of receiver to the Derwent water eſtate; and in the courſe of the year he obtained the ap pointment in a manner moſt flattering to himſelf, inaſmuch as his own merit carried the point in oppoſition to two other candidates who were ſtrongly recommended and powerfully ſupported. He was very happy in this appointment, particularly in the aſſiſtance which he received from Mr. Walton, the other receiver, who took upon himſelf the management of the accounts, leaving Mr. Smeaton leiſure and opportunity to exert his abilities on public works. In the year 1775, he had ſo much buſineſs as a civil engineer, that he wiſhed to reſign this appointment; but his friends prevailed on him to continue in office two years longer. After this, Mr. Smeaton was employed on many works of great public utility. He made the river Calder navigable, a work that required talents of the very firſt order, owing to the impetuous floods in that river; he planned and attended to the execution of the great canal in Scotland, for conveying the trade of the country either to the Atlantic or German ocean; and as a proof of the diſintereſtedneſs of his habits, having brought it to the place originally intended, he declined a handſome yearly ſalary, in order that he might attend to other buſineſs. On the opening of the great arch at London-bridge, the excavation around and under the ſtarlings was ſo conſiderable, that the bridge was thought to be in great danger of falling. Mr. Smeaton was then in Yorkſhire, and was ſent for expreſs, and he arrived without any delay. "I think," ſays his biographer, "that it was on a Saturday morning when the apprehenſion of the bridge was ſo general, that few perſons would venture to paſs over or under it. Mr. Smeaton applied himſelf immediately to examine it, and to ſound about the ſtarlings as minutely as poſſible, and the committee being called together, adopted his advice, which was to repurchaſe the ſtones that had been taken from the middle pier, then lying in Moorfields, and to throw them into the river to guard the ſtarlings. In this way Mr. Smeaton probably ſaved London-bridge from falling, and ſecured it till more effectual methods could be adopted."

Mr. Smeaton was appointed engineer to Ramſgate harbour, and brought it into a ſtate of great utility by various operations, of which he publiſhed an account in 1791. The variety of mills which Mr. Smeaton conſtructed, ſhews the great uſes which he made of his experiments already referred to; for it was a rule with him, from which he never willingly deviated, not to truſt to theory in any caſe, where he could have an opportunity to inveſtigate a ſubject by real trial. He built a ſteam-engine at Auſthorpe, and made a vaſt number of experiments with it to aſcertain the power of Newcomen's engine (ſee STEAM-*Engine*), which he improved and brought to a far greater degree of perfection, both in its conſtruction and powers, than it was before. Mr. Smeaton, during many years of his life, was a frequent attendant upon parliament, his opinion on various works begun or projected being continually called for. And in theſe caſes the ſtrength of his judgment and perſpicuity of expreſſion had full ſcope. It was his conſtant cuſtom, when applied to plan or ſupport any meaſure, to make himſelf fully maſter of the ſubject, to underſtand its merits and probable defects, before he would engage in it. By this caution, added to the clearneſs of his expreſſion, and the integrity of his heart, he ſeldom failed to obtain for the bill which he ſupported the ſanction of an act of parliament. No one was ever heard with more attention, nor had any one ever more confidence placed in his teſtimony. In the courts of law he had ſeveral compliments paid him from the bench by lord Mansfield and other judges, for the new light that he always threw upon difficult ſubjects. About the year 1785, the health of this excellent man began to decline, and he took the reſolution to avoid all the buſineſs he could, in order that he might have leiſure to publiſh an account of his inventions, improvements, and works, by which he conceived he ſhould be doing a public benefit to his country and the world. In September 1792, he had a paralytic ſeizure, which put a period to his life in about ſix weeks.

Mr. Smeaton had a warmth of expreſſion that might appear to thoſe who did not know him, to border upon harſhneſs, but thoſe more intimately acquainted with him knew that it aroſe from the intenſe application of his mind, which was always in the purſuit of truth, or engaged in ſome difficult ſubjects. If he were ſometimes apparently haſty and impetuous in his diſpoſition, he would always liſten to reaſon, and yield to the force of argument.

In all the ſocial duties of life he was exemplary: his manners were ſimple, and his mode of life abſtemious. He was ſingularly moderate in his pecuniary concerns. He was fond of ſcience for its own ſake, and ſpent much of his leiſure in cultivating that of aſtronomy; for which purpoſe, he fitted up an obſervatory in his houſe, furniſhed with curious contrivances of his own invention. He was a friend and encourager of merit wherever he diſcerned it, and many perſons were indebted to him for important aſſiſtance on their entrance into life. Mr. Smeaton was the inſtitutor, in 1771, of a ſociety of civil engineers, which was diſſolved at his death, but afterwards renewed; they publiſhed, in 1797, a volume of his Reports. For his works in conſtructing bridges, mills, harbours, engines, &c. ſee his Reports, in 3 vols. 4to. Of his inventions and improvements of philoſophical inſtruments, an idea may be formed from the liſt of his writings which is inſerted in Hutton's Dictionary.

Smelting

SMELTING, among *Metallists*, the melting of a metal from the ore in a smelting furnace; in order to separate the metallic parts from the sulphur and arsenic, and the earthy and strong substances of all kinds with which they are combined.

Smelting, in propriety, is restrained to large works, in which ores from the mines are melted down and separated.

In speaking of works in a lesser way, we do not say smelting, but *melting*.

In the more precious metals this is called *refining;* which see. And smelting is most commonly applied to the reduction of iron ores.

The art of smelting the ores of all metallic substances was, probably, at first very imperfect; hence the use of iron has every where been of a more recent date than that of the other metals, because it requires the application of a much stronger fire to smelt the ores of iron than those of any other metal. We have no certain accounts when, or by whom, the several metals were discovered. Wallerius says, that, as far as he knew, Pliny was the first who enumerated the six metals; but they were certainly known long before his age, and were mentioned both by Homer and by Moses, a much more ancient author. (Numb. xxxi. 22.) From this testimony we may certainly infer, that all the metals, anciently mentioned, were known, at least in the country of the Midianites, above fourteen hundred and fifty years before the birth of Christ, or near nine hundred years after the deluge. Moreover, iron and copper were, without doubt, known before the deluge, and probably all the other metals, which are more easily extracted from their ores than the former.

In the time of Abraham, however, gold and silver were esteemed, as they are at present, precious metals (Gen. xxiii. 16. Gen. xiii. 2.); and hence it is reasonable to conclude, that Noah was able to instruct his descendants in the art of smelting metallic ores; this art was afterwards lost among the various colonies, which quitted the plains of Asia in search of settlements; and as the earth, soon after the deluge, and long before it could have been peopled by the posterity of Noah, must have become covered with wood, and in process of time different countries might have been cleared by setting the wood on fire, which might flux metallic ores contiguous to the surface of the earth, it is not improbable, that the first idea of smelting ores might have been thus suggested to many nations. See Creech's Lucretius, vol. ii. p. 572.

We may hence conjecture, that the first rude process, by which metals were extracted from their ores, was that of putting a quantity of ore upon a heap of wood, and setting the pile on fire, in conformity to the manner, in which ores were smelted during the burning of forests; but as the force of the fire is greatly diminished by the dispersion of its flame, and as the air acts more forcibly in exciting fire, when it rushes upon it with greater velocity, it is likely that the heap of wood and ore would soon be surrounded with a wall of stone, in which sufficient openings would be left for the entrance of the air, and thus a kind of furnace would be constructed.

The Peruvians, we are told, had discovered the art of smelting and refining silver, either by the simple application of fire, or where the ore was more stubborn, and impregnated with foreign substances, by placing it in small ovens or furnaces on high grounds, so artificially constructed, that the draught of air performed the function of a bellows, a machine with which they were totally unacquainted. This method of smelting ores on high grounds, without the assistance of a bellows, or at least of bellows moved by water, seems to have been formerly practised in other countries as well as in Peru. There are several places in Derbyshire, called *boles* by the inhabitants, where lead has been anciently smelted, before the invention of moving bellows by water; these boles were always situated upon high grounds, and mostly upon that side of a hill which faces the west, probably because the wind proceeds most frequently from that quarter.

From a pig of lead, dug up in 1766 at one of these boles near Matlock, and bearing an inscription in relievo, from which it appears to have been smelted in the age of Adrian; many of the boles in Derbyshire seem to be of high antiquity. However, this method of smelting ore by the variable action of the wind, being a very troublesome and precarious process, has been universally disused, and the more regular blast of a bellows has been introduced in its stead.

The invention of the bellows is attributed by Strabo to Anacharsis, the Scythian; but he was probably the improver of this machine; for Homer, who lived long before his time, describes Vulcan as employing twenty pair of bellows at once in the formation of the shield of Achilles. Iliad, lib. xviii. v. 470.

When the art of moving bellows by means of a water-wheel was first discovered, is uncertain; the ancients seem to have been unacquainted with it; but we learn from Agricola (De Re Metal. published in 1550, pp. 165. 338.) that it was very generally known, at least among the Germans, in his time; for he speaks of it often, without hinting at its being a recent invention. By this advantageous contrivance, however, the moderns have, in many instances, worked over again, with considerable profit, the heaps of iron and other kinds of slag, from which the metal has been but imperfectly extracted, before the moving of the bellows by water was discovered.

About fifty years ago, the blast, or hearth-furnace, was the only one in use for smelting lead-ore in Derbyshire. In this furnace, ore and charcoal, or ore, and what is called *white coal,* which is wood dried but not charred, being placed, in alternate layers, upon a hearth properly constructed, the fire is raised by the blast of a bellows, moved

by a water-wheel; the ore is soon smelted by the violence of the fire, and the lead, as it is produced, trickles down a proper channel, into a place contrived for its reception. These ore-hearths are now very rare; though they are frequently applied to the extracting lead from the slag which is produced, either at the ore-hearth, or the cupola furnace, and they are then called *slag-hearths*, and the lead thus obtained is called *slag-lead;* the fire in a slag-hearth is made of the cinder of pit-coal instead of charcoal; the furnace called a *cupol*, or *cupola*, and *reverberatory* furnace, and by the Germans a *wind-furnace*, in which ores are smelted by the flame of pit-coal, is said to have been invented about the year 1698, by a physician named Wright; though Becher may, perhaps, be thought to have a prior claim to its invention, or introduction from Germany. But whoever was the first inventor of the cupola, it is now in general use, not only in Derbyshire and other counties for the smelting of ores of lead, but both at home and abroad, where it is called the *English furnace*, for the smelting of copper ores. This furnace is so contrived, that the ore is melted, not by coming into immediate contact with the fuel, but by the reverberations of the flame upon it. The bottom of the furnace, on which the lead-ore is placed, is somewhat concave, shelving from the sides towards the middle; its roof is low and arched, resembling the roof of a baker's oven: the fire is placed at one end of the furnace, upon an iron grate, to the bottom of which the air has free access; at the other end, opposite to the fire-place, is a high perpendicular chimney; the direction of the flame, when all the apertures in the sides of the furnace are closed up, is necessarily determined, by the stream of air which enters at the grate, towards the chimney, and in tending thither it strikes upon the roof of the furnace, and being reverberated from thence upon the ore soon melts it. This furnace does not require the use of bellows, and may, therefore, be constructed any where. In smelting lead-ore, they generally put into the cupola furnace a ton of ore, previously beat small and dressed, at one time, which quantity they call a *charge;* and they work off three charges of ore in every twenty-four hours. In about six hours from the time of charging, the ore becomes as fluid as milk. In order to obtain the lead free from the slag which swims over it, the smelters usually throw in about a bushel of lime, which dries up the slag, and prevents its running out with the lead. The slag, thus thickened, is raked up towards the sides of the furnace, and the lead gushes out through a hole in one of the sides of the furnace, which having been properly stopped during the smelting of the ore, is opened for this purpose into an iron pot, from which it is laded into iron moulds, containing what they call a pig of lead; the pigs, when cold, being ordinarily stamped with the maker's name, are sold under the name of *ore-lead*. After the lead has all flowed out of the furnace, they stop up the tap-hole, and drawing down the slag and lime into the middle of the furnace, they raise the fire, till the mixture of slag and lime, which they simply term *slag*, is rendered very liquid; upon this mass they throw another quantity of lime, and proceed as before. When the lead thus obtained, amounting generally to twenty or thirty pounds, is let out of the furnace, a new charge of ore is put in and the operation renewed.

In order to spare the time and expence of fuel, they have, in some furnaces, lately contrived a hole, through which they suffer the main part of the liquid slag to flow out, before they tap the furnace for the lead; upon the little remaining slag they throw a small portion of lime, and draw the mixture out of the furnace without smelting it. This kind of furnace they have nicknamed a *maccaroni*.

Dr. Watson has suggested some improvements in the construction of this furnace, and in the process of smelting above described. He proposes to substitute an horizontal chimney in the place of the perpendicular one now in use, and that the end farthest from the fire should be turned up by a tube of earthen-ware, or otherwise; so that the sulphureous acid, set at liberty during the burning of the sulphur, may issue out in a direction parallel to the flue of the chimney, and at the distance of about one foot and a half above it. Let a number of large globular vessels be made either of glass or lead, each of which must have two necks, so as to be capable of being inserted into one another: let these vessels be placed in the flue of the chimney, the neck of the first being inserted into the above-mentioned tube, and the neck of the last being left open, for fear of injuring the draught of the furnace. Let each of these globular vessels contain a small quantity of water, in which case, he apprehends, that the heat of the flue will raise the water into vapour, and that this watery vapour will be the means of condensing the sulphureous acid vapour, in such a degree as to render the undertaking profitable. When the sulphur is all consumed, the draught of the furnace may be suffered to have its ordinary exit at the end of the horizontal chimney, by a very slight contrivance of a moveable damper.

The same ingenious writer also observes, that very sulphureous ore should be roasted for a long time with a gentle heat. He also proposes to leave as little lead as possible in the slag; for this purpose he suggests, that it might be useful to throw a quantity of charcoal-dust upon the liquid scoria in the cupola furnace, in order that the calcined lead might be converted into lead, by uniting itself to the inflammable principle of the charcoal; and that it might be also useful to flux sulphureous lead-ores in conjunction with the scales or other refuse pieces of iron, or even with some sorts of iron-ore.

The smelter might farther find it worth his while to reduce the slag into a powder by a stamping mill, or to grind it by any other contrivance, and then he may separate the stony part of the slag from the metallic, by washing the whole in water, inasmuch as the metallic part is heavier than the other. Watson's Chem. Ess. vol. iii. p. 253, &c.

The other furnaces used in smelting are supplied with large bellows, moved by the arbor of a wheel, which is turned round by a current of water. These have obtained different names, according to some difference in their construction. Their greater or less height gives occasion also to the distinction of *high furnaces* and *middle furnaces*. The high furnaces are of modern invention; they were first introduced at Mansfelt in 1727, and are now used in almost all countries where ores are smelted, as in Saxony, Bohemia, Hungary, &c. They contribute, by their great height, being above eighteen feet high, which allows the ore to undergo a roasting by different degrees of heat before it is melted, to simplify and diminish the labour. They are chiefly employed for crude fusions, and particularly for the slate copper-ore.

In order to facilitate the extraction of metallic substances from the ores and minerals containing them, some operations, previous to the fusion or smelting of these ores and minerals, are generally necessary. These operations consist of, 1. The *separation* of the ores and metallic matter from the adhering unmetallic earths and stones, by hammers, and other mechanical instruments, or by washing with water. 2. Their *division* or reduction into smaller parts by contusion and trituration, that by another washing with water they may be more perfectly cleansed from extraneous matters, and rendered fitter for the subsequent operations. 3. *Roast-*

ing, or *calcination*, the uſes of which operation are to expel the volatile, uſeleſs, or noxious ſubſtances, as water, vitriolic acid, ſulphur, and arſenic; to render the ore more friable and fitter for the ſubſequent contuſion and fuſion; and, laſtly, to calcine and deſtroy the viler metals; for inſtance, the iron copper-ores, by means of the fire, and of the ſulphur and arſenic. Stones, as quartz and flints, containing metallic veins or particles, are frequently made red-hot, and then extinguiſhed in cold water, that they may be rendered ſufficiently friable and pulverable, to allow the ſeparation of the metallic particles.

Roaſting is unneceſſary for native metals; for ſome of the richer gold and ſilver-ores; for ſome lead-ores, the ſulphur of which may be ſeparated during the fuſion; and for many calciform ores, as theſe do not generally contain any ſulphur and arſenic.

In the roaſting of ores, the following attentions muſt be given: 1. To reduce the mineral previouſly into ſmall lumps, that the ſurface may be increaſed; but they muſt not be ſo ſmall, nor placed ſo compactly, as to prevent the paſſage of the air and flame. 2. The larger pieces muſt be placed at the bottom of the pile, where the greateſt heat is. 3. The heat muſt be gradually applied, that the ſulphur may not be melted, which would greatly retard its expulſion; and that the ſpars, fluors, and ſtones, intermixed with the ore, may not crack, fly, and be diſperſed. 4. The ores not thoroughly roaſted by one operation muſt be expoſed to a ſecond. 5. The fire may be increaſed towards the end, that the noxious matters more ſtrongly adhering may be expelled. 6. Fuel which yields much flame, as wood and foſſile coals free from ſulphur, is ſaid to be preferable to charcoal or çoaks. Sometimes cold water is thrown on the calcined ore at the end of the operation, while the ore is yet hot, to render it more friable.

No general rule can be given concerning the duration or degree of the fire, theſe being very various according to the difference of the ores. A roaſting during a few hours or days is ſufficient for many ores; while ſome, ſuch as the ore of Rammelſberg, require that it ſhould be continued during ſeveral months.

Schlutter enumerates five methods of roaſting ores. 1. By conſtructing a pile of ores and fuel placed in alternate ſtrata, in the open air, without any furnace. 2. By confining ſuch a pile within walls, but without a roof. 3. By placing the pile under a roof, without lateral walls. 4. By placing the pile in a furnace conſiſting of walls and a roof. 5. By roaſting the ore in a reverberatory furnace, in which it muſt be continually ſtirred with an iron rod.

Several kinds of *fuſions of ores* may be diſtinguiſhed. 1. When a ſulphureous ore is mixed with much earthy matter, from which it cannot be eaſily ſeparated, by mechanical operations, it is frequently melted, in order to diſengage it from theſe earthy matters, and to concentrate its metallic contents. By this fuſion, ſome of the ſulphur is diſſipated, and the ore is reduced to a ſtate intermediate betwixt that of ore and of metal. It is then called a *matt* (lapis ſulphureo-metallicus), and is to be afterwards treated like a pure ore by the ſecond kind of fuſion, which is properly the ſmelting, or extraction of metal by fuſion. 2. By this fuſion or ſmelting, the metal is extracted from the ore previouſly prepared by the above operations, if theſe be neceſſary.

The ores of ſome very fuſible metals, as of biſmuth, may be ſmelted by applying a heat ſufficient only to melt the metals, which are thereby ſeparated from the adhering extraneous matters. This ſeparation of metals by fuſion, without the vitrification of extraneous matters, may be called *eliquation*. Generally, a complete fuſion of the ore and vitrification of the earthy matters are neceſſary for the perfect ſeparation of the contained metals. By this method, metals are obtained from their ores, ſometimes pure, and ſometimes mixed with other metallic ſubſtances, from which they muſt be afterwards ſeparated. To procure this ſeparation of metals from ores, theſe muſt be ſo thinly liquefied, that the ſmall metallic particles may diſengage themſelves from the ſcoria; but it muſt not be ſo thin as to allow the metal to precipitate before it be perfectly diſengaged from any adhering extraneous matter, or to pervade and deſtroy the containing veſſels and furnace. Some ores are ſufficiently fuſible; but others require certain additions, called *fluxes*, to promote their fuſion, and the vitrification of their unmetallic parts; and alſo to render the ſcoria ſufficiently thin to allow of the ſeparation of the metallic particles.

Different fluxes are ſuitable to different ores, according to the quality of the ore, and of the matrix, or ſtone adherent to it.

The matrixes of two different ores of the ſame metal frequently ſerve as fluxes to each other; as, for inſtance, an argillaceous matrix with one that is calcareous; theſe two earths being diſpoſed to vitrification when mixed, though each of them is ſingly infuſible. For this reaſon, two or more different ores to be ſmelted are frequently mixed together.

The ores alſo of different metals require different fluxes. Thus, calcareous earth is found to be beſt ſuited to iron ores, and ſpars and ſcoria to fuſible ores of copper.

The fluxes moſt frequently employed in the ſmelting of ores, are calcareous earth, fluors or vitreous ſpars, quartz, and ſand, fuſible ſtones, as ſlates, baſaltes, the ſeveral kinds of ſcoria, and pyrites.

Calcareous earth is uſed to facilitate the fuſion of ores of iron, and of ſome of the poorer ores of copper, and, in general, of ores mixed with argillaceous earths, or with felſpar. This earth has been ſometimes added with a view of ſeparating the ſulphur, to which it very readily unites: but by this union, the ſulphur is detained, and a hepar is formed, which readily diſſolves iron and other metals, and ſo firmly adheres to them, that they cannot be ſeparated without more difficulty than they could from the original ore. This addition is therefore not to be made till the ſulphur be previouſly well expelled.

Fluors, or fuſible ſpars, facilitate the fuſion of moſt metallic minerals, and alſo of calcareous and argillaceous earths, of ſteatites, aſbeſtus, and of ſome other infuſible ſtones, but not of ſiliceous earths without a mixture of calcareous earth.

Quartz is ſometimes added in the fuſion of ferruginous copper ores, the uſe of which is ſaid chiefly to be, to enable the ore to receive greater heat, and to give a more perfect vitrification to the ferruginous ſcoria.

The fuſible ſtones, or ſlates, baſaltes, are ſo tenacious and thick when fuſed, that they cannot be conſidered properly as fluxes, but as matters added to leſſen the too great liquidity of ſome very fuſible minerals.

The ſcoria obtained in the fuſion of an ore is frequently uſeful to facilitate the fuſion of an ore of the ſame metal, and ſometimes even of the ores of other metals.

Sulphurated pyrites greatly promotes the fuſibility of the ſcoria of metals, from the ſulphur it contains. It is chiefly added to difficultly fuſible copper ores, to form the ſulphureous compounds called *matts*, that the ores thus brought into fuſion, may be ſeparated from the adhering earthy matters, and that the ferruginous matter contained in them may

be deſtroyed, during the ſubſequent calcination and fuſion, by means of the ſulphur.

As in the ores called *calciform*, the metallic matter exiſts in a calcined ſtate; and as calcination reduces the metals of mineraliſed ores (excepting the perfect metals) to that ſtate alſo; therefore all calciform and calcined ores require the addition of ſome *inflammable ſubſtance* to reduce them to a metallic ſtate. In great works, the charcoal or other fuel uſed to maintain the fire, produces alſo this effect.

Metals are ſometimes added in the fuſion of ores of other more valuable metals, to abſorb from theſe ſulphur and arſenic. Thus, iron is added to ſulphurated cupreous and ſilver ores. Metals are alſo added in the fuſion of ores of other more valuable metals, to unite with and collect the ſmall particles of theſe diſperſed through much earthy matter, and thus to aſſiſt their precipitation. With theſe intentions, lead is frequently added to ores and minerals containing gold, ſilver, and copper.

Ores of metals are alſo ſometimes added to aſſiſt the precipitation of more valuable metals. Thus, antimony is frequently added to aſſiſt the precipitation of gold intermixed with other metallic matters. Macquer's Chem. Dict. Eng. edit. art. *Smelting*, note *m*. See Copper, Gold, Iron, Lead, Silver, Tin, &c. See alſo Schlutter's Treatiſe on the Smelting of Ores, tranſlated from the German into French by M. Hellot, and Chem. Dict. art. *Smelting*, Eng. ed. notes *n*, *o*, *p*, *q*.

The following ſimple method of ſmelting is practiſed by the natives of the province of Mekran in Perſia; which, although it may, at times, leave a trifling portion of the earth mixed with the metal, is, from its ingenuity, worthy of notice. When a ſufficient quantity of the ore is collected, it is placed upon a pile of wood, which is ſet on fire, and conſtantly repleniſhed with freſh fuel, until the ore melts and falls to the bottom, when it is ſeparated from the aſhes, and found to be conſiderably clearer than when firſt taken from the mine. It is then placed in a pit, made of earthen tiles, ſo conſtructed as to admit a fire under it. The ore is again melted in this pit, and a conſiderable quantity of the droſs and dirt removed, by ſkimming the ſurface. After this proceſs, the metal is lifted out in a liquid ſtate, poured into hollow cylinders of clay, and then ſold.

Smelting-*Houſe*, a houſe where they run and melt the ore into lead: one of theſe will run a ton in ten or twelve hours; but a fodder is their uſual day's work, that is, twenty-two hundred and an half weight.

Soap

SOAP, in *Chemiſtry*, is a name for thoſe bodies which are compounds of the alkalies with fat and the fixed oils. The earths and the other metallic oxyds alſo combine with fat and oils, forming neutral compounds. The former have been called earthy, and the latter metallic ſoaps.

The ſoaps formed by the alkalies have the diſtinguiſhing character of being ſoluble in water and alcohol. The earthy

ſoaps are perfectly inſoluble. And ſince any of the earths have a ſtronger attraction for oil than the alkalies, the alkaline ſoaps are always decompoſed by the earths. This occaſions the curdy appearance when ſoap is uſed with water containing any earthy or metallic ſalt. It is from this quality that waters are ſaid to be hard.

The earthy ſoaps are of a greyiſh-white colour, of a curdy appearance. The metallic ſoaps are of different colours. Both theſe and the earthy ſoaps are formed by adding a ſolution of an alkaline ſoap to a ſolution of an earthy or metallic ſalt. A precipitate is formed, which is the ſoap to be obtained. With a ſolution of iron containing the red oxyd, the ſoap is of an orange-red colour. It has the conſiſtency of a ſalve or plaſter, but by expoſure to the air it becomes dry and friable, but may be ſoftened by heat. When a ſimilar ſolution of ſoap is added to a ſolution of ſulphate of copper, a green ſoap is formed, which is a fluxible maſs like wax. Corroſive ſublimate, treated in this manner, gives a red ſoap. All the metallic oxyds may be combined with fat or oil in a ſimilar way.

Soap, in the *Manufactures* and *Domeſtic Economy*. This is confined to ſoaps made with the fixed alkalies, combined with different kinds of fat and oil. Theſe, in the manufacture of ſoap, are divided into two principal varieties, *viz*. hard and ſoft.

1. *Hard Soap*.—The alkali employed for hard ſoap is ſoda, generally obtained from the different ſea vegetables, and called by different names, according to the name of the plant in different countries. Moſt of the *algæ*, but particularly the *fucus* and *ſalſola*, afford ſoda by burning. The vegetables are firſt dried, and then burnt in pits formed with looſe ſtones. The earthy matter and the ſoda, with ſome neutral ſalts, fuſe into a crude maſs, in which ſtate it is ſold. This ſubſtance is furniſhed in great abundance from the Highlands of Scotland, under the name of *kelp*, and from Alicant in Spain, under the name of *barilla*. In France it is known by the name of *varec*; this being the name of the plant from which it is generally produced there.

It is commonly, however, in this ſtate that it comes to the ſoap-maker, varying frequently in its value, and often occaſioning much uncertainty in its employment. It ſhould be the firſt buſineſs, therefore, of the manufacturer, to aſſay the ſubſtance from which he gets his alkali, even before he purchaſes it. For this purpoſe a given quantity ſhould be dried and weighed. After reducing it to powder, it muſt be treated with hot rain-water, till the water coming from it has no taſte, reſerving all the portions of water added from time to time. Concentrate this liquid by evaporation, till the quantity of liquid is not more than three times the weight of the quantity taken to be aſſayed. Now weigh out a quantity of ſulphuric acid, ſay half the weight of the aſſay. From this quantity take ſmall portions at a time, and add them to the ſolution above-mentioned, ſtirring it at the ſame time with a wooden rod. When the eſcape of gas begins to diminiſh on the addition of freſh acid, let the additional portions be very ſmall. Now take bits of paper ſtained blue with litmus: on dipping one into the liquid, if more acid is wanting, the paper will not be changed, but the moment the paper is turned red by the liquid, ceaſe to add ſulphuric acid. Let the remaining acid be now weighed, in order to know what has been uſed, and note this down. Now take pure ſal ſoda (carbonate of ſoda) in well-formed cryſtals, exactly of the ſame weight with the firſt aſſay, and diſſolve it in three times its weight of pure water. Weigh out the ſame quantity of ſulphuric acid as before, and juſt follow the ſame ſteps as above directed, till the litmus paper juſt turns red, then weigh the remaining acid, to obtain the quantity uſed, and note down as before. Then ſay, as the acid conſumed by the ſal ſoda is to that conſumed by the aſſay, ſo is 100 to a number which will give the *per centage* of carbonate of ſoda contained in the crude alkali. Thirty *per cent*. of the carbonate of ſoda ſo indicated will be real ſoda, the only ſubſtance which combines with the fat to form ſoap. When the exact value of the alkali is known, it is then to be treated as follows, to prepare it for mixing with the fat.

The kelp or barilla is firſt to be pounded, and then mixed with one-fifth its weight of quicklime, in a large vat. Theſe vats are generally three or four in number to each boiler. They are frequently made with brick-work, from four to five-feet cubes, but ſometimes of caſt-iron. Beſides theſe vats for the infuſion of crude alkali, each of theſe has a ſimilar cavity under it. The bottom of the vat is even with the ground, the under vat being ſunk below, and is intended to receive the liquor which runs from a plug-hole in the upper vat, when the infuſion has gone on to a certain extent. One of theſe vats, with its under reſervoir, is ſufficient for one boiling, but they are generally all at work, in order to give time for the ſolution of the alkali from the crude maſs.

In charging a vat, the barilla, kelp, or potaſh, and ſometimes mixtures of theſe, are firſt coarſely powdered, and mixed with quicklime alſo coarſely powdered; ſome water is then thrown upon theſe to ſlake the lime. In the ſide of the vat ſome ſtraw is firſt placed about the plug-hole, to prevent bits from paſſing through. The vat is now charged, and water poured upon the materials till it ſtands conſiderably above the ſolid maſs. After ſtanding ſeveral hours the plug is withdrawn, to let out the ſolution into the lower reſervoir. The plug is now returned, and freſh water poured upon the materials. Some or all the firſt ley is now removed into one of the other lower reſervoirs before the ſecond infuſion is drawn off. This is done, that the ſoap-boiler may always have at command two leys of different degrees of ſtrength, as in the courſe of every boiling he finds it neceſſary to uſe ſometimes the weak and at other times the ſtrong.

The number of waters to be added to the materials depends upon the judgment of the workman, who by his taſte can tell when the water has diſſolved the whole of the alkali. The times of charging the vats are irregular with reſpect to the times of charging the boiler. Some one of the vats is conſtantly employed, in order to inſure a conſtant ſupply of the ley.

The boilers are made to hold from about 20 to 25 cwt. of ſoap; they are made in two parts, the lower part being about three feet in diameter, and the ſame in length: under the bottom of this the fire acts. The top part has a flange, to which the upper part is ſcrewed. The latter is nearly an hemiſphere, riſing above the floor juſt ſufficient to allow the workman to ſtir the ſoap when he ſtands up.

The ley being ready to lade out of the reſervoir, which is near to the boiler, the tallow or oil firſt weighed is put in. When it is ſufficiently melted, the workman begins by adding the ley, and ſtirring the mixture. The alkali and the oil ſoon begin to unite, forming a milky fluid. As more ley is added, and the ſtirring continued, the liquid thickens. This is continued generally for 30 hours, and frequently more, till ſmall portions of the ſoap, taken out from time to time, aſſume a proper conſiſtence, which the workman by conſtant experience underſtands. He now adds a quantity of common ſalt, which has the effect of ſeparating the watery part from the ſoap, which contains a portion of neutral ſalts, that exiſted in the crude alkali, and ſometimes alſo free alkali, eſpecially when more than enough has been added. The fire is now to be withdrawn, and the maſs left to cool. The watery part will be found at the bottom, and

requires to be pumped out by a pump, which is a fixture on the ſide of the boiler. When this has been removed the fire is rekindled, and if the maſs does not melt freely, a little water is added. As ſoon as the whole becomes liquid, and is made uniform by agitation with wooden poles, the fire is again withdrawn, and the maſs allowed to aſſume a proper conſiſtence for lading. It is laded into ſquare moulds: theſe are compoſed of a number of ſtrata lying one upon another, ſo that when the ſoap has become ſolid, each layer of frame-work can be removed, beginning at the top, and the ſoap is cut into cakes with a piece of ſmall braſs wire at every interval: theſe cakes are afterwards cut into ſquare priſmatic pieces, in which ſtate they are ſold.

Some manufacturers proceed in a different manner in boiling the ſoap. In the method above deſcribed, and which is practiſed by a judicious ſoap-boiler in Derby, the watery part, or what is called the ſpent ley, is not ſeparated till all the ley is added. This method is called cloſe working, becauſe the liquid is of an uniform thickneſs all the time, till the ſalt is added: it then aſſumes what is called the granular form, in which the watery part is ſeparated from the ſoap, like the whey and the curd in making cheeſe. This ariſes from the ſoap being inſoluble in ſalt-water. In this ſtate the ſoap is ſaid to be open, to diſtinguiſh it from the ſtate in which it exiſts before the ſalt is added, and in which the ſoap is ſaid to be cloſed. In the open working the common ſalt is added at ſeveral intervals, in order to keep the ſoap ſeparated from the water. The fire is alſo withdrawn ſeveral times, and as many times the ſpent leys are pumped off. After each time, except the laſt, freſh ley is added and the ſtirring repeated. The proper ſtate for the ſoap is known by the appearance of the bubbles. The very hard ſoap, or that which is made with all ſoda, is not the moſt convenient for practice; it is neither ſo fit for waſhing the hands, nor ſo eaſily reducible to a pulpy ſtate for the different manufactures in which it is employed. The hard white ſoap, produced in the manufactory above alluded to, is in great repute from its whiteneſs and its proper conſiſtency. This ſoap is formed with tallow and a mixture of ſoda and potaſh. The boiler holds from about 25 to 27 cwt. of ſoap. The following are the average proportions of the materials employed; 13 cwt. 2 qr. 16 lbs. of tallow, 5 cwt. 3 qr. 12 lbs. barilla, 3 cwt. 2 qr. 6 lbs. American potaſh, 4 cwt. 2 qr. 7 lbs. quicklime, and 3 qr. 16 lbs. common ſalt (muriate of ſoda.) Theſe materials produce 1 ton 4 cwt. 0 qr. 1 lb. of white ſoap. The lime, the barilla, and the potaſh, are mixed together, and placed in the vat already deſcribed. In order to furniſh the ley which is added to the melted tallow, the lime is employed merely to rob the potaſh and ſoda of their carbonic acid, and of courſe does not enter into the compoſition of the ſoap. The neutral ſalts, which both the barilla and potaſh contain, are pumped out with the ſpent leys with a portion of uncombined alkali: of this we ſhall ſay ſomething hereafter.

Hence it will appear, that the ſoap is a compound of pure alkali, with the fat, and a portion of water.

In the making of ſoap, as in all other chemical combinations, the proportions appear to be definite. Every ſoap-boiler knows, that where too much ley is added to the fat, the exceſs will be found in the watery part under the ſoap; and that if the fat were in exceſs, the ſoap would be greaſy to the feel, and would otherwiſe ſhew the preſence of uncombined fat. Hence it will be found on analyſis, that the proportions will be uniform, becauſe they are definite. The quantity of ſoda which combines with olive-oil and tallow, is about 30 of the former to 212 of the latter; and ſince an atom of potaſh is to that of ſoda as 29.25 to 44.5, 45 of potaſh will combine with 212 of oil or tallow.

The following is an analyſis of ſoap by Darcet, Lelievre, and Pelletier:

Oil -	
Soda -	
Water -	
	100

If the alkali were potaſh inſtead of ſoda, then the proportions would be,

Oil - - -	
Potaſh - - -	
Water - - -	
	100

In the firſt of theſe analyſes, the ſoda is to the oil as 85 to 609, or as 1 to 7.28 nearly. In the ſecond, the potaſh is to the oil as 12.3 to 58.4, or as 1 to 4.6 nearly. The ſpecimen of ſoap before alluded to contains a mixture of potaſh and ſoda. The 3 cwt. 2 qr. 6 lbs. of American potaſh, according to the average value of that article, ought to give 2 cwt. 2 qr. of pure potaſh. By the above analyſis, the 1 ton 4 cwt. 0 qr. 1 lb. of ſoap ought to contain 7 cwt. 1 qr. 7 lbs. of water. There ought to be therefore only 16 cwt. 3 qr. 21 lbs. of the alkali and tallow. It appears, that in forming this ſpecimen of ſoap, 100 lbs. of common ſalt were added, which gives to the ſoap 55.5 lbs. of ſoda, and takes away from it 83.25 lbs. of potaſh. Hence, the alkali reſulting from the potaſh in this ſoap will be 1 cwt. 3 qr., and 55.5 lbs. of ſoda derived from the common ſalt, or 2 qr. 4 lbs. nearly. In order to know what ſoda is derived from the barilla, we muſt ſubtract the tallow and the alkali from the whole; that is (16 cwt. 2 qr. 27 lbs.) 1 cwt. 3 qr. of potaſh, 2 qr. of ſoda, and 13 cwt. 2 qr. 16 lbs. of tallow, will leave 3 qr. 6 lbs. of ſoda derived from the barilla.

The proportions of the ſoap in queſtion will, therefore, be, in 2689 lbs. of ſoap,

Tallow	1528	or
Soda -	146	
Potaſh -	196	
Water -	819	
		100

This reſult, although it contains a little too much of the mixed alkali to correſpond with theory, is ſtrikingly near the truth. We may therefore conclude, that ſoap, in general, contains from 8 to 12 *per cent.* of alkali, as more or leſs of each prevails, and about 30 *per cent.* of water. The hardeſt white ſoap made with ſoda would contain 8 *per cent.*; and the ſoft ſoap, in which potaſh alone is uſed, would be a little more than 12 *per cent.*

In the above ſpecimen of hard ſoap, it will be ſeen that 398 lbs. of crude potaſh furniſh 280 lbs. of real alkali, which is ſeven-tenths of the whole. With this were employed 656 lbs. of barilla, which furniſh 90 lbs. of real alkali. Now 192 lbs. of American potaſh will produce 135 lbs. of pure potaſh, and this will diſengage from 126 lbs. of muriate of ſoda, or common ſalt, 90 lbs. of pure ſoda. Hence 192 lbs. of American potaſh and 126 lbs. of ſalt will produce as much ſoda as 656 lbs. of barilla.

This weight of barilla, at the preſent price, coſts 10*l.* 5*s.*: 192 lbs. of potaſh will now coſt 6*l.* 17*s.*; and 126 lbs. of common ſalt, 1*l.* 17*s.* Theſe two ſums are 8*l.* 14*s.* The ſaving, therefore, in employing potaſh and common ſalt, in making even the beſt hard white ſoap, inſtead of barilla, is nearly 5 *per cent.* But if the two alkalies are to be contained in equal proportions, then about half the common ſalt only need be uſed, and the ſaving will be very conſiderable. It will alſo appear evident, that ſoap may be made of any degree of hardneſs, by uſing more or leſs of common ſalt with the potaſh; and that if no ſalt at all be uſed, the ſoap will be ſoft.

The difference of price between barilla and potaſh is often much more than at preſent in favour of uſing potaſh: this will make the ſaving above mentioned more conſpicuous.

It muſt alſo be remembered, that ſome ſalt is always uſed for the purpoſe of ſeparating the ſpent leys from the ſoap. This has been ſtated at about three-quarters of a cwt. to 24 cwt. of ſoap. It ſeems that a ſolution of ſalt of this ſtrength does not diſſolve ſoap.

Hard Soap, Yellow.—This ſoap is formed of ſimilar proportions of ſoda and tallow with the laſt; but it alſo contains roſin, and ſometimes palm oil.

The following are the average proportions of the materials for making yellow ſoap, which may be relied upon.

Tallow.	Roſin.	Palm Oil.	Barilla.	Potaſh.	Lime.	Soap produced.
Cwt. qr. lb. 13 0 11	3 2 18	1 0 0	6 2 14	1 0 16	5 0 9	26 1 21

The whole weight of the materials, excluſive of the lime, and the refuſe of the potaſh and barilla, is equal to 24 cwt. 0 qr. 1 lb.; the ſoap, independent of the water it contains, is 18 cwt. 0 qr. 25 lbs.: thus, taken from 24 cwt. 0 qr. 1 lb. leaves 5 cwt. 3 qr. 4 lbs. for the refuſe of the tallow, roſin, and palm oil. That the tallow muſt make much waſte will be eaſily conceived, from the moſt inferior kind being uſed. The roſin and oil muſt alſo yield much refuſe. This refuſe is found all together at the bottom of the pan after boiling, and is known in the manufactories under the name of *nigre.*

In boiling the yellow ſoap, the roſin, oil, and tallow are put into the boiler firſt. The ley is prepared in a ſimilar vat, and managed in other reſpects in the ſame mode as in forming the white ſoap.

The manner too of adding the ley from time to time, and the ſtirring, are juſt kept up in a ſimilar way, till the fatty matter is fully ſaturated. The time required for boiling the quantity of ſoap ſtated above, is ſometimes as much as three weeks, during which time it is kept in what is called the open ſtate, that is, the watery part is completely ſeparated from the ſoap. It would appear that this ſoap requires merely the preſence of the neutral ſalts in ley to keep it in the open ſtate. This ariſes probably from this being a leſs perfect ſoap, and leſs ſoluble in water. The ſoap appears in ſmall lumps, perfectly detached from the fluid. At the end of every day the ſoap is allowed to cool, when the thin part ſinks to the bottom: this is ſpent ley, and is pumped off every morning. The fire is again raiſed, and freſh leys added: the boiling and ſtirring go on again. This action is repeated till the fat is ſaid to be killed. This, as we have obſerved, takes ſometimes fifteen or twenty days. When this change is complete the fire is withdrawn, and the maſs allowed to cool: the laſt ley is pumped out. The addition of a little water, and the fire being raiſed, allow the ſoap to be diſſolved, and the refuſe, which is principally the ſubſtance we have called nigre, is left at the bottom, perfectly diſtinct from the ſoap. When the ſoap is of a proper conſiſtence for caking, it is transferred to the moulds, where it is treated in a manner ſimilar to that already deſcribed in the white ſoap.

It is a queſtion, whether making this inferior ſoap is ſo profitable to the manufacturer as is ſuppoſed. It has appeared, that in making the quantity of ſoap above ſtated, which is 26 cwt. 0 qr. 21 lbs., there are 5 cwt. 3 qr. 4 lbs. of refuſe, which is principally in the nigre. This refuſe will be found very trifling in the white ſoap; we think not more than $\frac{1}{24}$th of the weight of the ſoap. It will be evident, that in making the yellow ſoap, a great quantity of matter is uſed which never combines. Would it not be more economical to purify theſe materials before hand?

Soft Soap.—This differs in its compoſition from hard, in containing no alkali, but potaſh. We have ſeen that hard ſoap may be made not only with pure ſoda, as is the caſe in the manufactories in the ſouth of France, but that a tolerably hard ſoap, much better fitted for practice, is made with about equal portions of potaſh and ſoda.

Soft ſoap made with colourleſs fat, ſuch as tallow, is a white unctuous ſubſtance, about the conſiſtency of lard. If the fat be coloured, the ſoap partakes of the ſame. In France and other parts of the continent, it is generally coloured, ſometimes with metallic oxyds. Thoſe made with yellow oil are ſometimes coloured with indigo, which gives them a green colour. The oils employed are ſeldom olive-oil, but the cheaper oils, ſuch as rape-oil, the oil of hemp-ſeed, lint-ſeed, and others.

In Holland it was made with whale-oil. This oil was forbidden on ſome parts of the continent, on account of its diſagreeable ſmell. In this country, however, all the ſoft ſoaps are made with whale-oil, which gives a tranſparent maſs of a yellow colour. In commerce, however, we do not find it uniform in its colour. Beſides the yellow part, it appears interſperſed with white ſpots, giving the whole a ſtrong reſemblance to the inſide of a dried fig.

The proportions of potaſh and oil, for forming ſoft ſoap, will be eaſily inferred from what has been obſerved in the proportions of the other ſoaps. The white ſpecks are produced by adding a portion of tallow to the oil, when the boiler is charged. This addition does not improve the ſoap, but habit in commerce has rendered it indiſpenſable. The ley is prepared by adding to the potaſh about three-fourths its weight of quicklime, and the proceſs is continued as directed in making the hard ſoap, uſing the ſame apparatus. The ley, when prepared, is to be added to the oil and tallow in the boiler at intervals, ſimilar to thoſe in making the hard ſoap, and the ſtirring kept up in the ſame way, till the maſs aſſumes a proper conſiſtency. The experienced ſoap-maker will judge, when the materials are in proper proportions, by the appearance of the ſoap when boiling; hence he knows when to ceaſe to add more ley. Should a ſtranger to the proceſs of making either kind of ſoap have to perform the taſk, he would require to know the proportions in which the alkali ought to bear to the oil. He would weigh his oil or tallow when he put it into the boiler; he will aſſay his ley by the method laid down in the commencement of this article, and by that means know how much real alkali is contained in a given meaſure of his ley. He will by this means know nearly when he had added a ſufficient quantity of ley to ſaturate the oil or fat. In the ſoap made with ſoda, the real alkali muſt be to the oil as 1 to 7.28, and that with all potaſh muſt be as 1 to 5.1 nearly. This of courſe will be the proportion for ſoft ſoap. When the ſoft ſoap is

of a proper confiftency for caking, it is poured into barrels, in which it is fold.

Soaps, particularly the hard, are frequently reduced in their value, by the fraudulent practice of keeping them wet. The common or proper ftate is when they contain about 30 *per cent.* of water; but they may, by a nefarious management, be made to contain 60 *per cent.* which is a great impofition. This fraud, like many others, is detected when it is too late. It is found to lofe weight rapidly by expofure to the air.

Before we clofe this article, we may point out fome means of economizing the ufe of the alkali in foap-making, which, in very extenfive manufactories, is worth attending to. In the firft place, it fhould be obferved, that the fpent leys always contain free alkali, and it is generally added a fecond time, in order that as much as poffible of it may be taken up. It is found, however, by experience, that fome will ftill be found in folution, which the fat will never take up. This is owing to the fame liquid containing feveral neutral falts in folution. If this liquor be evaporated to a certain extent, and fet to cool in fhallow veffels, the neutral falts will cryftallize and feparate from the liquid to a certain extent. The liquid part may then be evaporated a fecond time, and again cryftallized. The liquid, after thefe falts have been feparated, may now be added to the fat, and the alkali will combine with it. If barilla or kelp is the alkali, then the liquid ought to have a little lime added, which evaporating, ferves to take the carbonic acid from the foda. Without this precaution the carbonate of foda would cryftallize with the other falts. With potafh this precaution is unneceffary.

The falts which are feparated from barilla and kelp are chiefly muriate and fulphate of foda. The former may be ufed as a fubftitute for falt in the laft part of the procefs of boiling. The fulphate of foda may be fufed with fawduft or powdered coal in a reverberatory-furnace. The fulphuret of foda is produced, from which the alkali may be recovered. Perfumed foaps are eafily formed by adding the different effential oils while the foap is in a liquid form, but not while very hot, becaufe the perfume would evaporate. The faponaceous liquid, called milk of rofes, is formed by mixing the liquid obtained by expofing potafh to the air with rofe-water, and then adding this to oil of almonds, till the mixture becomes milky without being greafy.

Ball Soap, commonly ufed in the North, is made with lees from afhes and tallow. The lees are put into the copper, and boiled till the watery part is quite gone, and there remains nothing in the copper but a fort of faline matter (the very ftrength or effence of the ley); to this the tallow is put, and the copper is kept boiling and ftirring for above half an hour, in which time the foap is made; and then it is put out of the copper into tubs, or bafkets, with fheets in them, and immediately (whilft foft) made into balls. Note, it requires nearly twenty-four hours, in this procefs, to boil away the watery part of the ley.

The fimpleft, and upon the whole the moft beautiful, foap, is the fine white foap prepared from olive-oil and foda, extracted from the beft barilla, which is manufactured largely in the countries where the olive grows; particularly in the fouth of France, for which Marfeilles is the moft celebrated, in fome parts of Italy, and in Tripoli. A fimilar, but more expenfive foap, is made of foda and oil of almonds for medicinal purpofes. (See SAPO *Amygdalinus.*) What is called in our country "Windfor foap" is of this kind, prepared with either of the above-mentioned oils. Common foap is manufactured principally by our foap-boilers from tallow or any other fat; and the alkali employed is either barilla or pearl-afh, or a mixture of the two, according to the price and the practice of the manufacturer. But in order to obtain a ftiff falt, recourfe is had to the action of common falt, as we have already mentioned. The olive-oil, or Marfeilles and other foaps, are fometimes artificially "marbled," or ftreaked throughout their whole fubftance with red or blue veins. This foap is harder than the white foap of the fame materials, becaufe it requires to be dried to a greater degree in order to take the marbling. This is performed, by adding to the foap, as foon as it is completely made and feparated from the fpent ley, a frefh quantity of ley, and immediately afterwards a folution of fulphate of iron. A decompofition between the two takes place, and a black oxyd of iron is feparated, which is entangled within the liquid foap. The boiler is then cooled, and the ley which fettles is drawn off; after which the foap is again melted. A workman then ftands over the boiler, and ftirs the foap with a wooden inftrument, while another throws in at intervals a quantity of colcothar, or brown-red oxyd of iron, ground up with water into an uniform liquid. This diffufes both the oxyds through the foap, which is then cooled and framed. This procefs requires fome manual dexterity, fo that the ingredients may be ftirred together, and the marbling fufficiently diffufed through the whole mafs, without mixing it completely.

Soap is much ufed in wafhing and whitening linens, cleanfing woollen cloths from oil, whitening filk, and freeing it from the refinous varnifh with which it is naturally covered; and for various other purpofes, by the dyers, perfumers, hatters, fullers, &c.

The alkaline lixiviums, being capable of diffolving oils more effectually than foap, might be employed for the fame purpofes; but when this activity is not mitigated by oil, as it is in foap, they are capable of altering, and even deftroying entirely, by their caufticity, moft fubftances, efpecially animal matters, as filk, wool, and others; whereas foap cleanfes from oil almoft as effectually as pure alkali, without danger of altering or deftroying, which renders it very ufeful.

The manufacture of foap in London, firft began in the year 1524; before which time this city was ferved with white foap from foreign countries, and with grey foap, fpeckled with white, from Briftol, and fold for a penny a pound, and alfo black foap for a halfpenny the pound.

SOAP, in the *Materia Medica.* Soaps, both hard and foft, have been applied to medical ufe. Well made hard foap, fit for medical ufe, has very little odour, and a naufeous alkalefcent tafte; is white, and of a firm confiftence; does not feel greafy, and is devoid of any faline efflorefcence on the furface. With water it forms a milky opaque folution; and with alcohol a nearly tranfparent, fomewhat gelatinous, folution. It is decompofed by all the acids, and by many neutral falts, which combine with the alkali and form new compounds; hence hard water which contains fulphate of lime does not properly diffolve foap. According to the experiments of Darcet, Lelievre, and Pelletier, (ftated in the preceding article,) 100 parts of newly made foap confift of 60.94 oil, 8.56 alkali, and 0.503 water: but part of the water is loft by keeping, and the foap becomes lighter.

Hard foap, triturated with vegetable refins and thick balfams, incorporates with them into a compound; foluble, like the foap itfelf, in watery liquors; hence it proves an ufeful ingredient in refinous pills, which of themfelves are apt to pafs entire through the inteftines, but by the admixture of foap become diffoluble in the ftomach. It renders

unctuous and thick animal matters diffoluble in like manner in aqueous fluids, and hence may be prefumed to act as a menftruum for thefe kinds of fubftances in the body, that is, to attenuate vifcid juices and refolve obftructions: fuch, in effect, are the virtues which it appears to exert in cachectic, hydropic, and icteric cafes, in which laft, particularly, its aperient and refolvent powers have been often experienced. Solutions of it have been likewife found to diffolve certain animal concretions of the harder kind, as the filaments which are fometimes feen floating in the urine of rheumatic and arthritic perfons, the matter fecreted in gouty joints, and the more compact urinary calculus; on thefe fubftances (at leaft in the latter), though foap of itfelf acts more languidly than lime-water, yet, when joined to that menftruum, it remarkably increafes its activity; the diffolving power of a compofition of the two being, according to Dr. Whytt's experiments, confiderably greater than that of the foap and lime-water unmixed: of the good effects of thefe medicines in calculous cafes there are feveral inftances; but what their effects may be in gouty and rheumatic ones is not yet well known. See LITHONTRIPTICS, STEPHENS's *Medicine*, &c. and STONE.

Soap is regarded, in the materia medica, as purgative and lithontriptic; externally applied it is ftimulant and detersive. For internal ufe the hard foap only is employed. It is occafionally ordered in habitual coftivenefs, and in jaundice, combined with rhubarb, or fome bitter extract; but its power as a purgative is very limited, and it cannot act in any other way in relieving jaundice. It is more ufeful in calculous habits, in which, however, its action is altogether confined to the ftomach; for as foap is decompofed by the weakeft acids, its alkaline bafe corrects the acidity fo prevalent in the ftomachs of calculous patints, and thus at leaft affifts in checking the increafe of the difeafe. Soap is alfo beneficial in decompofing metallic poifons when taken into the ftomach; and, as it is the antidote which can moft readily be procured, fhould always be early reforted to. It is neceffary in this latter cafe to give it in folution; of which a teacupful fhould be drunk at fhort intervals, till the effects expected from it be produced. In other cafes it is preferable to give it in fubftance. The dofe may be from grs. v to ʒfs, made into pills.

As an external remedy, foap is efficacioufly ufed in frictions to fprains and bruifes; and much benefit has been derived from rubbing the tumid bellies of children labouring under mefenteric fever, with a ftrong lather of foap every morning and evening.

From the properties of foap we may know, that it muft be a very effectual and convenient anti-acid. It abforbs acids as powerfully as pure alkalies and abforbent earths, without having the caufticity of the former, and without oppreffing the ftomach by its weight, like the latter. Soap is alfo one of the beft antidotes to ftop quickly, and with the leaft inconvenience, the bad effects of acid corrofive poifons, as aqua fortis, corrofive fublimate, &c.

Soap is employed externally for difcuffing rheumatic pains, arthritic tumours, the humours ftagnating after fprains, &c. Some pretend that the indurated tophaceous concretions in arthritic joints, have been refolved by the external ufe of foapy cataplafms. Several compofitions for external purpofes are prepared in the fhops.

The officinal preparations of foap are as follow: *viz.* "Pills of foap with opium," of Lond. Ph.; "Pills of compound fquill;" "Aloetic pills" of Ed. Ph.; "Pills of aloes and affafœtida." (See PILLS.) "Pills of aloes and ginger," of the Dub. Ph. are compounded of 1 oz. of hepatic aloes, 1 dr. of ginger-root in powder, ½ oz. of foap, and ½ dr. of effential oil of peppermint: let the aloes and ginger be rubbed together to a powder; then add the foap and the oil fo as to form a mafs. This is an ufeful pill, and ufed with advantage for obviating the habitual coftivenefs of the fedentary, and of leucophlegmatic habits. The dofe is from grs. x to grs. xv, or more:— "Soap plafter." (See EMPLASTRUM *Saponis*, and SOAP PLASTER.) "Cerate of foap," of the Lond. Ph. is compofed of 8 oz. of hard foap, 10 oz. of yellow wax, 1 lb. of femivitreous oxyd of lead powdered, a pint of olive-oil, and a gallon of vinegar. Boil the vinegar on the oxyd of lead over a flow fire, ftirring diligently till they incorporate; then add the foap, and boil again in a fimilar manner, until the moifture be entirely evaporated; and, laftly, mix with the oil the wax previoufly melted. This cerate is occafionally ufed as a cooling dreffing. For the "compound foap liniment" of the Lond. Ph. fee LINIMENT. The "Tincture of foap," commonly called "Liniment of foap," of the Ed. Ph., is prepared by digefting 4 oz. of foap fliced in 2 lbs. of alcohol for three days, and then adding 2 oz. of camphor, and ½ oz. of the volatile oil of rofemary, frequently fhaking the mixture. Thefe preparations are ftimulant and anodyne, and may be beneficially applied againft local pains, and in bruifes, rubbed upon the parts. "The tincture of foap and opium" of Ed. Ph., commonly called "Anodyne liniment," is made in the fame manner, and from the fame ingredients as the other tincture of foap, only adding, at the beginning of the procefs, one ounce of opium. The addition of the opium to the foap liniment renders it, in many cafes of rheumatifm and local pains, more ufeful than the fimple liniment.

The anodyne balfam, commonly called Bates's balfam, is prepared by digefting two ounces of foap and half an ounce of opium, in a gentle fand-heat, for three days, with eighteen ounces of rectified fpirit of wine, and then adding fix drachms of camphor and one drachm of oil of rofemary to the ftrained liquor. This compofition, with the addition of opium, is fuppofed to be more effectual for allaying violent pains than the common opodeldoc: it is alfo given internally in nervous colics, jaundices, &c.

Soft foap is confiderably more acrid than the hard foap, and it is, therefore, employed only for fome external purpofes: a mixture of equal parts of our common foft foap and quicklime is ufed as a mild cauftic. Lewis's Mat. Med. Thomfon's Lond. Difp.

SOAP, *Almond.* See SAPO *Amygdalinus*, and SOAP, *fupra.*

SOAP, *Ammoniacal*, a white faponaceous compound, readily made by fhaking any oil with liquid ammonia, which is much ufed medicinally as a ftimulating application; but the union between thefe two is much weaker than between the fixed alkalies and oil, fo that this will not harden; and by keeping for fome time, the ingredients will partly feparate. In order to effect a more intimate union between them, muriated ammonia muft be added to common foap.

SOAP-*Lees.* See LIXIVIUM *Saponarium.*

The term *foap-lees* is fometimes ufed technically to denote the "fpent ley," which is pumped out of the vat or ciftern, after the foap has feparated; and which, being more or lefs alkaline, is referved either to be ufed again, or to be evaporated, fo that the refidue may be calcined for extracting the alkali.

SOAP, *Starkey's*, is a combination of fixed vegetable alkali with effential oil of turpentine. It is fo called from its inventor, who combined falt of tartar (carbonate of potafh) with this oil, and obtained a faponaceous compound, to

which many medicinal virtues have been afcribed. It enters alfo into the compofition of pills, named alfo from Starkey. As fixed alkalies are very difficultly made to unite with effential oils, Starkey found no other expedient for the preparation of his foap, than time and patience. His method confifts in putting dry alkali into a matrafs, and pouring upon it effential oil of turpentine to a height equal to the breadth of two or three fingers: in five or fix months part of the alkali and oil will be thus combined together, and form a foap, which muft be feparated from the mixture, and more of it will be afterwards formed in the fame manner. The moft commodious method, fays Dr. Lewis, of obtaining the combination, is by throwing the falt, red-hot, into a heated mortar, immediately reducing it to powder; then pouring on it, whilft hot, by little at a time, an equal quantity, or more, of the oil, and continuing to grind them together, fo as to form a fmooth foft mafs. Stahl, Rouelle, Beaumé, &c. have publifhed proceffes for this combination. Mr. Beaumé fays, that it may be made in a few hours by triturating, during a long time, alkaline falt upon a porphyry, and adding to this falt, during the trituration, oil of turpentine. This medicine, which has an acrid alkaline tafte, and is very apt to deliquiate on being expofed to air, was formerly celebrated, under the denomination of foap of tartar, univerfal corrector, &c. as a diuretic in nephritic complaints, and as a corrector of certain vegetables, particularly of opium: its virtues have not been fully determined by experience, nor does the prefent practice pay any regard to it.

Soap, *Volatile*, is of three kinds, *viz.* one compofed of fixed alkalies and volatile oils; another of volatile alkalies and oils of the groffer or more fixed kind; and the third, in which both the alkali and the oil are volatile. Of the firft kind is Starkey's foap: thofe of the fecond fort are obtained more readily. (See Linimentum *Volatile*, and Epithem *Volatile*.) Combinations of the latter kind, in a liquid form, have been defcribed under Salts; and compofitions of the fame kinds may be obtained in a folid ftate, by mixing the falt with the oil, and fubliming them together.

Soap, *Laws relating to.* By 17 Geo. III. c. 52. no perfon, within the limits of the head office of excife in London, fhall be permitted to make any foap, unlefs he occupy a tenement of 10*l.* a year, and be affeffed to, and pay the parifh rates; or elfewhere, unlefs he be affeffed to, and pay to church and poor. By 24 Geo. III. c. 41. and 43 Geo. III. c. 69. every foap-maker fhall annually take out a licence, for which he fhall pay 2*l.* By 43 Geo. III. c. 68. fched. (A), certain duties are laid on foap imported, as therein ftated; and upon the exportation of foap made in Great Britain, and which hath paid the duties, the fame fhall be drawn back, by 43 Geo. III. c. 69. fched. (C): but no drawback fhall be allowed on the exportation of foreign foap imported. (27 Geo. II. c. 21.) By 43 Geo. III. c. 69. fched. (A), certain duties are impofed on foap made in Great Britain; and certain allowances fhall be made for foap ufed in the manufactures of Great Britain, fched. (C). Places of making are to be entered on pain of 200*l.* (10 Ann. c. 19. 47 Geo. III. feff. 2. c. 30.); and covers and locks to be provided under a forfeiture of 100*l.* (5 Geo. III. c. 43. 12 Geo. III. c. 40.) The furnace-door of every utenfil ufed in the manufacture of foap fhall be locked by the excife officer, as foon as the fire is damped or drawn out, and faftenings provided; and opening or damaging fuch faftening incurs a penalty of 100*l.* (17 Geo. III. c. 52. 24 Geo. III. c. 48. feff. 2.) Officers are required to enter and furvey at all times, by day or night, and the penalty of obftructing is 50*l.*; and they may unlock and examine every copper, &c. between the hours of five in the morning and eleven in the evening, and the penalty of obftructing is 100*l.* No foap-maker fhall have any private pipe or conveyance, on pain of 200*l.*; and the penalty of obftructing an officer who fearches for it is 100*l.* No maker fhall have more than one moveable pump, on penalty of 500*l.* Every maker of foap, before he begins any making, if within the bills of mortality, fhall give twelve hours, if elfewhere, twenty-four hours' notice, in writing, to the officer, of the time when he intends to begin, on pain of 100*l.* No maker fhall remove any foap unfurveyed, on pain of 20*l.*, without giving proper notice of his intention. And if any maker fhall conceal any foap or materials, he fhall forfeit the fame, and alfo 500*l.* (1 Geo. III. ftat. 2. c. 36.) And the penalty of privately making foap is forfeiture of the foap and materials, and 100*l.* (5 Geo. III. c. 43.) Perfons affifting in making foap privately fhall forfeit, for the firft offence, 20*l.*; for the fecond, 40*l.* or be liable to four months' imprifonment till it be paid. (47 Geo. III. feff. 2. c. 30.) Owners or renters of houfes where foap fhall be privately made forfeit 200*l.* Every barrel of foap fhall contain 256 lbs. avoirdupois, half-barrel 128 lbs., firkin 64 lbs., half-firkin 32 lbs., befides the weight or tare of each cafk; and all foap, excepting hard cake foap and ball foap, fhall be put into fuch cafks and no other, on pain of forfeiture and 5*l.* (10 Ann. c. 19. 12 Ann. ft. 2. c. 9.) The maker fhall weekly enter in writing at the next office the foap made by him in each week, with the weight and quantity at each boiling, on pain of 50*l.*; and within one week after entry clear off the duties, on pain of double duty. (17 Geo. III. c. 52.) Cockets granted for fhipping foap to be conveyed to any other part of the kingdom, fhall exprefs the quality, quantity, and weight, the mark of the package, by whom made and fold, and where configned, under penalty of forfeiture and feizure of the fame and package. (23 Geo. II. c. 21.) No foap fhall be imported, otherwife than in fome package, containing at leaft 224 pounds of hard foap, on pain of feizure and forfeiture, and alfo package; and the mafter of the veffel fhall forfeit 50*l.* If any perfon fhall knowingly harbour or conceal any foap, unlawfully imported, or relanded after fhipping for exportation upon debenture, he fhall forfeit 50*l.* for every hundred weight, together with the goods and package. The maker fhall keep juft fcales and weights, where he makes his foap, and permit and affift the officer to ufe them, on pain of 10*l.* (10 Ann. c. 19.) And by 10 Geo. III. c. 44. for infufficient fcales and weights, he fhall forfeit 100*l.*

Soap-*Afhes*, in *Agriculture*, the refufe of foap-boilers, fometimes termed foapers' afhes. See Ashes.

Soap *Refufe*, the compounds of oil, tallow, and other fubftances, with lime and pot-afh, which are often met with and ufed as manures. Moft forts of foapy mixtures are found to have much effect in promoting vegetation.

Soap-fuds, or the wafhings of this fort which are left and thrown away from large mills and manufactories, fuch as thofe of the filk and other fimilar kinds, are found highly beneficial as manures themfelves, or for being mixed and blended up with other matters in this intention. The farmers, in fome places, collect them by the hogfhead, at the rate of from 6*d.* to 1*s.*, and mix them up with earthy materials, fo as to form rich compofts, in confequence of their containing portions of animal matter, gum, and alkali, efpecially when taken from filk works. And the common foap-fuds, which are generally wafted and thrown away, are faid to have been found of great utility in cold moift meadows; and would probably be more fo, if employed in com-

27669

bination with rich earthy fubftances. All the various refufe matters of this fort fhould be collected, as they are capable of being ufed in this way with advantage to the farmer. See SALINE *Manures*.

Solder

SOLDER, Sodder, or *Soder*, formed from the French *ſoudure*, of the Latin *ſolidare, to ſtrengthen:* is a metallic compoſition, uſed in ſoldering or joining together other metals.

For this purpoſe, it is required that ſolders melt ſooner than the metal to be ſoldered, that they adhere firmly to its ſurface, and that they approach as near as may be to the metal ſoldered in hardneſs and colour.

The different ſolders are made of gold, ſilver, copper, tin, biſmuth, and lead; uſually obſerving, that in the compoſition there be ſome of the metal to be ſoldered mixed with ſome higher and finer metals.

The ſolder for gold is compoſed of fine gold, with one-fourth or one-half its weight of fine ſilver, accurately mixed together by fuſion, and afterwards beat out into leaves, ſomewhat thinner than card-paper, and rendered as ſoft as

But as this ſolder does not melt without a conſiderable degree of heat, it cannot be uſed when it is inconvenient to heat the work red-hot; and therefore, in this caſe, copper and braſs are ſoldered with ſilver.

Though ſpelter ſolder be much cheaper than ſilver ſolder, yet workmen in many caſes prefer the latter. And Mr. Boyle informs us, that he has found it run with ſo moderate a heat, as not much to endanger the melting of the delicate parts of the work to be ſoldered; and if well made, this ſilver ſolder will lie even upon the ordinary kind itſelf; and ſo fill up thoſe little cavities that may chance to be left in the firſt operation, which is not eaſily done without a ſolder more eaſily fuſible than the firſt made uſe of. Works Abridged, vol. i. p. 135.

As to iron, it is ſufficient that it be heated red-hot, and

as to make the colour of the folder correfpond, as nearly as may be, to that of the piece. A mixture of gold and copper is alfo a folder for fine copper as well as for fine gold.

Gold being particularly difpofed to unite with iron, this metal, with a high alloy of copper, proves an excellent folder for the finer kinds of fteel inftruments.

For larger works in iron and fteel, copper, or an alloy compofed of equal parts of tin and iron, is employed.

The folder ufed by plumbers is made of two pounds of lead to one of block-tin. Its goodnefs is tried by melting it, and pouring the bignefs of a crown-piece on a table; for, if good, there will arife little, bright, fhining ftars in it.

For filver, two kinds of folder, *viz.* the hard and foft, are ufed and applied like the gold folder. The hard folder is compofed of equal parts of filver and fine brafs, and the foft is prepared by fufing the hard folder with $\frac{1}{10}$th its weight of pure zinc. Another folder for filver may be formed of two parts of fine filver and one part of brafs, taking care that thefe are not long kept in fufion, left the brafs fly off in fumes. For coarfer filver, a folder is prepared by melting four parts of fine filver and three of brafs, throwing in a little borax, and pouring it out as foon as it is melted.

The folder for copper is made like that of the plumbers; only with copper and tin; and for very nice works, inftead of tin, they fometimes ufe a quantity of filver.

For copper, brafs, and the hard alloys of copper, the beft hard folder, fays Aikin (Dict.), is compofed of brafs and zinc, in the proportion of from eight to fixteen of the former to one of the latter, according to the required hardnefs. The foft folder is compofed of three parts of zinc and one of lead, and is applied by means of a common foldering iron, made red-hot.

Solder for tin is made of two-thirds of tin and one of lead, or of equal parts of each; but where the work is any thing delicate, as in organ-pipes, where the juncture is fcarcely difcernible, it is made of one part of bifmuth, and three parts of pewter.

The pewterers ufe a kind of folder made with two parts of tin and one of bifmuth: this compofition melts with the leaft heat of any of the folders.

The folder for tin, pewter, and lead (or the plumber's folder), fays Aikin (ubi fupra), is of two kinds: the leaft fufible is compofed of equal parts of tin and lead; the more fufible contains, befides, bifmuth in various proportions. A very good foft folder is prepared by melting together fixteen parts of tin, eight of lead, and four of bifmuth.

Spelter folder is made of one part of brafs and two of fpelter, and is ufed by the braziers and copper-fmiths for foldering brafs, copper, and iron. This folder is improved by adding to each ounce of it one pennyweight of filver. But as this folder does not melt without a confiderable degree of heat, it cannot be ufed when it is inconvenient to heat the work red-hot; and therefore, in this cafe, copper and brafs are foldered with filver.

Though fpelter folder be much cheaper than filver folder, yet workmen in many cafes prefer the latter. And Mr. Boyle informs us, that he has found it run with fo moderate a heat, as not much to endanger the melting of the delicate parts of the work to be foldered; and if well made, this filver folder will lie even upon the ordinary kind itfelf; and fo fill up thofe little cavities that may chance to be left in the firft operation, which is not eafily done without a folder more eafily fufible than the firft made ufe of. Works Abridged, vol. i. p. 135.

As to iron, it is fufficient that it be heated red-hot, and the two extremities, in this ftate, be hammered together. By this means they become incorporated one with the other: when it is foldered it is ufually done with brafs; good tough brafs, with borax applied, mixed with water to the confiftence of pafte.

The duke of Florence's nail, anciently fo much admired, as being half iron and half gold, whereas thofe two metals were deemed irreconcileable, was joined by a kind of folder made by Turneiffer, an ingenious chemift of Venice; the fecret of which was never difcovered till publifhed by Tachenius. This folder is nothing but a little copper, or cyprus vitriol, put between the gold and the iron. For, naturally, the great acidity of the gold reduces the iron into a fcoria or ruft, when the two are applied over one another; but this inconvenience is removed, by the interpofition of a little copper, be it in the fmalleft quantity imaginable. See the next article.

SOLDERING, or SODDERING, among *Mechanics*, the joining and faftening together of two pieces of the fame metal, or of two different metals, by the fufion and application of fome metallic compofition on the extremities of the metals to be joined.

In foldering, fome artifice is neceffary to make the folder and metals adhere. All the metals, except filver and gold, upon melting, or before, are covered with drofs: and all the folders have fome of thefe metals in them: this drofs hinders the folder and metal from uniting, and it is neceffary to remove it. This is not performed in every kind of foldering by the fame materials. The plumbers effect this by greafing the lead, laying on the folder, and melting it with a hot iron, and thus the drofs, generated in fufion, unites with the greafe, and flows away from the melted metal. The glaziers and tin-men ufe rofin in powder for the fame purpofe; for all inflammable fubftances that will melt are equally conducive to this ufe. When copper and brafs are foldered with pewter, the work is firft wafhed with a folution of fal ammoniac in water, then heated juft hot enough to melt the pewter, and the pewter applied to the joint to be foldered. In foldering that requires a greater heat, borax is ufed.

Thus, in foldering gold, and alfo filver, take a piece of folder of the proper fize and fhape, and lay it on the part to be cemented, and fprinkle it over with pulverized borax; then apply the flame of a blow-pipe, which will caufe both the borax and folder to fufe, the latter incorporating with, and adhering firmly to, the gold. When the juncture is complete, the piece is left to cool, and the borax is removed by boiling water, or, what is ftill better, a little dilute fulphuric or muriatic acid. It is obferved, that the folder will, in this cafe, appear confiderably paler than the other part, both on account of the filver with which it is alloyed, and of the borax, which always lowers the colour of the gold. This defect, however, may be remedied by melting on the furface of the folder a mixture of two parts of nitre and one of burnt alum, and afterwards wafhing it off with a foft brufh and hot water; by which the natural colour of the gold will be reftored, and even heightened. Others direct this operation to be performed by joining together the pieces propofed to be united with fine foft iron wire, and touching the joint to be foldered with a camel's hair pencil, dipped in borax finely powdered, and well moiftened with water; and then placing a little folder upon the joint, and applying upon it a large piece of charcoal, and, with a blow-pipe and lamp, blowing upon it through the flame, until it melts the folder; and thus the work is finifhed. In order to cleanfe filver or gold, after it is foldered, make it juft red-hot, and let it cool; then boil it in alum-water, in

an earthen veſſel, and it will be as clean as when new. If it be gold, boil it in urine and ſal ammoniac.

For a method of ſoldering, particularly uſeful to optical and mathematical inſtrument-makers, ſee GRINDING *of Metallic Specula*.

Spinning

SPINNING, the art of combining animal or vegetable *fibres into threads or cords, by twiſting them together.* Wool, ſilk, cotton, flax, and hemp, are the matters moſt commonly employed for ſpinning into threads; and of theſe, *moſt of the vegetable fibres, except cotton, require to be* wetted during the operation of ſpinning, to render them *more* ſupple; but cotton, wool, and ſilk, are ſpun in a dry ſtate.

The machines *employed for ſpinning are of very different*

kinds, and adapted to the materials to be operated upon; but they have all a ſpindle, revolving with a rapid motion, to twiſt the fibres which are attached to the end of it, and are ſupplied in a regular quantity, as faſt as the twiſting motion of the ſpindle will form them into a thread; and there is alſo ſome proviſion of a bobbin upon the ſpindle, to take up and retain the thread when made.

The moſt ancient mode of ſpinning is by the ſpindle and diſtaff, and this method is the ſimpleſt of all others. The ſpindle is nothing more than a piece of hard wood, made round, and ſharp-pointed at one end, ſo that it can be made to ſpin upon its point, in the ſame manner as a child's top: the upper part is reduced to a pin or peg, and it is this part which has the fibres united to it, the lower or enlarged part being only to give ſufficient weight to make it ſpin. The ſpinner muſt be ſeated upon the ground, and after having put the diſtaff in motion upon its point, by twirling it between the hands, get it up to a rapid motion, by ſtriking it occaſionally with the hand, with a motion very ſimilar to that by which a child keeps up the motion of his whipping-top, when he draws the laſh of a whip round it.

The flax, or material which is to be ſpun, after being properly prepared, is lapped round the end of the diſtaff, which is nothing more than a ſtick that the ſpinner holds in the left hand, ſo as to be conveniently ſituated to draw off from it a few fibres at a time, with the finger and thumb of the right hand, to form the thread. The upper part of the ſpindle, which is made ſmaller, like a pin, has the ends of the fibres which are to form the thread attached to it before it is put in motion. Theſe fibres are drawn out of the bunch which is wound upon the diſtaff, and held between the finger and thumb, ſo as to be in the direction of the length of the ſpindle; therefore, when the ſpindle is once made to revolve, it twiſts theſe fibres together, to form a thread, and as faſt as the thread forms, the ſpinner draws off more flax from the diſtaff, and guides the fibres between the finger and thumb, ſo that they ſhall be regularly delivered out, and make an even thread. The motion of the ſpindle is conſtantly kept up, by ſtriking it as often as the hand can be ſpared from the operation of guiding the thread. When by theſe means as great a length of thread is formed as is convenient to reach from the end of it to the ſpindle, the thread is wound upon the outſide of the ſmall part or pin of the ſpindle, for which purpoſe the ſpinner applies the fore-finger againſt the thread, cloſe to the end of the ſpindle, and bends the thread at that part, ſo that it will be at right angles with the direction of the ſpindle, inſtead of being nearly in the direction of its length; and alſo, that it will be guided oppoſite to the middle of the pin, or ſmall part of the ſpindle, inſtead of being at the extreme end thereof. In this ſituation the motion of the ſpindle, which is continually kept up, occaſions the thread to wind up, or lap upon the pin of the ſpindle, inſtead of twiſting round upon itſelf, as in the former caſe; but when nearly all the length of thread is thus diſpoſed of, the finger is removed from the thread, and it immediately aſſumes its original direction, by ſlipping to the extreme end of the ſpindle, ſo as to be twiſted round itſelf by the motion of the ſpindle, and more fibres are now ſupplied to it from the bunch upon the diſtaff, to form a freſh length of thread. In this manner the ſpinning proceeds, until as much thread is ſpun and wound upon the pin of the ſpindle as will make a moderate ſized ball.

This ſimple and inconvenient method of ſpinning becomes very efficient, when the ſpindle, inſtead of being ſpun upon the ground, is mounted in a proper frame, and turned by a wheel and band; this forms a machine which is called the one-thread wheel, and is ſtill uſed in the country for ſpinning wool: the ſpindle is made of iron, and placed horizontally, ſo that it can revolve freely; and the extremity of the ſpindle, to which the thread is applied, projects beyond the ſupport.

The wheel which turns it is placed at one ſide, the pivots of both being ſupported in upright pieces, riſing up from a ſort of ſtool. The ſpinner puts the wheel in rapid motion by its handle, and its weight is ſufficient to continue the motion for ſome ſeconds; then walking backwards from the ſpindle, in the direction of its length, ſhe ſupplies the fibres regularly, and the motion twiſts them into a thread; but when a convenient length is ſpun, the ſpinner ſteps on one ſide, and reaches out that arm which holds the end of the thread, ſo as to alter the direction of the thread, and bring it nearly perpendicular to the length of the ſpindle, which motion gathers or winds up the thread upon the middle of the projecting part of the ſpindle. This being done, ſhe holds the thread in the direction of the ſpindle, ſo that it will receive twiſt, and retreats again to ſpin a freſh length of thread. For ſpinning wool, it is not wound round the diſtaff the ſame as flax, but the ſpinner holds a lock of it, doubled over the fore-finger, and draws away the fibres from the middle part of the lock, to do which with regularity is the great art of ſpinning by hand.

A ſpinning-machine more perfect than this is the one-thread flax-wheel, with ſpindle and flyer; it has the property of conſtantly drawing up the thread as faſt as it is ſpun, inſtead of ſpinning a length, and then winding it upon the ſpindle. For this purpoſe the ſpindle is made longer than the other, and is turned by a band and wheel; but the wheel receives motion from the foot by a ſmall treadle, becauſe the ſpinner ſits before the wheel to work the ſpindle, which is ſupported upon its two extreme ends, and near one end the flyer is fixed; this is a piece of wood curved to an arc, the vertex of which is fixed on the ſpindle, and from the extremities of the arc two arms proceed, ſo as to be parallel to the ſpindle, and at ſuch a diſtance from it as to admit a wooden bobbin to be fitted looſely upon the ſpindle; and at the ſame time the arms of the flyer can revolve round the bobbin without touching it. The end of the thread is faſtened to the bobbin, and conducted through a hook fixed in the flyer, ſo that it proceeds from the circumference of the bobbin to this hook, in a direction perpendicular to the bobbin, but turns round the hook ſo as to come into the direction of the ſpindle. The thread is then conducted through a perforation made in the centre of the end of the ſpindle or pivot, upon which it revolves, and to this end of the thread the fibres are ſupplied. The twiſting motion given by the revolution of the ſpindle forms them into a continuation of the thread, which is gathered up upon the bobbin as faſt as the ſpinner lets it go through her fingers, by a tendency which the bobbin has to turn ſlowly, at the ſame time that the flyer to which the thread is hooked is revolving rapidly round the bobbin. For this purpoſe a ſtring is paſſed round a ſmall neck upon the bobbin, and one end of the ſtring being faſtened to the frame, the other has a ſmall weight to draw it tight round the neck of the bobbin, and occaſion friction. In other ſpinning-wheels, a ſecond band from the great wheel is made to turn the bobbin more ſlowly than the ſpindle. The thread which paſſes over the hook of the flyer is rapidly carried round the circumference of the bobbin; but as the bobbin follows the motion of the flyer, it only winds up as much thread upon the bobbin as the difference of the two motions;

and this tendency to wind up can be increafed or diminifhed at pleafure, by the friction which is occafioned by the ftring or band which paffes round the neck of the bobbin. When the winding-up of the thread upon the bobbin has accumulated a ridge of thread upon it oppofite to the hook in the flyer, the thread muft be fhifted to another hook oppofite to a different part of the bobbin, for which purpofe the arms of the flyer are furnifhed with different hooks, and this muft be repeated feveral times, until the whole length of the bobbin is filled; it is then taken off to be reeled, and replaced by another empty bobbin.

An improvement was made in the fpinning-wheel by Mr. Antis fome years ago, which was an application of what fir Richard Arkwright had before invented. The object is to obviate the neceffity of ftopping the wheel to remove the thread from one hook to another, in the manner juft defcribed. For this purpofe, the bobbin is made to move regularly backwards and forwards upon the fpindle a fpace equal to its length, fo that every part will, in fucceffion, be prefented oppofite the hook over which the thread paffes, and thus receive the thread regularly upon the whole length of the bobbin. The additional parts neceffary for producing this movement are as follow: a pinion of only a fingle leaf is made to project from the extremity of the pivot of the great wheel, or a worm or endlefs fcrew formed on the end pivot, will anfwer the fame purpofe, which is to actuate a wheel of feven inches diameter, and ninety-feven teeth; therefore ninety-feven revolutions of the great wheel will produce one revolution of this fmaller wheel; upon the face of which a circular ring of wire is fixed, and fupported from the wheel by fix legs, fo as to be oblique to the plane of the wheel, as it touches it at one part, and at the oppofite fide of the ring projects nearly three-fourths of an inch. This ring of wire gives motion to an upright lever, about fifteen inches long, and moving on a centre at three inches from its lower extremity, where it has a pin fixed in it, and refting againft the oblique ring of wire; therefore, when the wheel turns round, it communicates a fmall motion to the lever, in confequence of its obliquity to the plane in which it revolves. The upper end of the lever is connected to an horizontal fliding-bar, fituated beneath the fpindle, and having an upright piece of brafs, which works in the notch of a pulley, formed on the end of the bobbin, and drives the bobbin backwards and forwards upon the fpindle, according as the oblique ring of wire forces the pin at the lower end of the lever in or out, when the wheel moves round. To regulate and return this alternate motion, a fmall weight hangs by a line to the fliding-bar, and, paffing over a pulley, rifes and falls as the bobbin recedes and advances, and tends conftantly to keep the pin at the lower end of the lever in contact with the wire. It is evident, from this defcription, that one ftaple only is wanted to the arms of the flyer, which being placed near the extremity, the thread paffes through it, and by the motion of the bobbin, is laid regularly upon it from one end to the other.

The invention has alfo another advantage over the old method, which always winds the thread in ridges upon the bobbin; and if the thread breaks in reeling the yarn, the whole bobbin may as well be thrown away, becaufe the thread cannot eafily be found again; but this improved wheel always winds the threads acrofs upon one another, by which means the end can never be loft.

In order to regulate the friction on the bobbin, and retard its motion in a greater or lefs degree at pleafure, there is a neck of brafs or fteel faftened to one end of it, and embraced by a kind of fmall vice, or pincers, fixed to the fliding-bar. This vice muft be made either with two elaftic fprings with wooden tops, or of wood wholly, and faced with leather; but if made of wood only, then a fpring muft be made beneath the fhoulder of the fcrew, to anfwer the fame purpofe. By tightening this fcrew more or lefs, the friction on the bobbin may be regulated to the greateft nicety, provided the fprings are of a ftrength rightly proportioned to their functions. It will readily appear, that all this may be done without the leaft effect on the velocity of the whole machine, as thereby nothing is added to the general friction fo as to obftruct it.

It was not until the latter end of the laft century, that fpinning-machines of greater powers were conftructed; but all threads were fpun by one of the machines which we have defcribed; the firft being ufed for cotton and wool, and the other, with the bobbin and flyer, for flax; but for very coarfe threads, two fpindles were applied to the latter machine, and the fpinner having the wool wound round a band, tied it round her waift, inftead of winding it upon a diftaff, and was thus able to draw out fibres with each hand, and fupply two fpindles. And of the other fimple fpindles, feveral were made to turn together by the movement of one large horizontal wheel, around which the fpindles were arranged in directions radiating from the centre, and each fpindle received a rapid motion by the contact of the edge of the large wheel, which was turned round by one perfon. The fpinners each ftood oppofite to his refpective fpindle, fo as altogether to occupy a large apartment, and by this means they could do much more work than formerly, having none of the interruptions of turning the wheel.

The firft improvement of any importance in fpinning, was that of, the fpinning-jenny, invented by Hargraves, as related in our article COTTON; and the machine itfelf will be defcribed under the article WOOLLEN *Manufacture*. This machine confifts of a number of fpindles, fimilar to thofe of the one-thread wheel, which are all mounted, in a perpendicular direction in the fame frame, and turned round by one large wheel, fituated in an horizontal direction, and put in motion by a crank at the upper end of its fpindle. The threads from each fpindle are conducted nearly in an horizontal direction, but being quite at the point or upper extremity of the fpindles, do not wind upon the fpindles, but will receive twift, becaufe the threads flip over the top of the fpindles as they revolve. The threads are guided between two rulers of wood, called the *clafps*, inftead of the finger and thumb of the fpinner. Thefe rulers are made to fit together, fo as to hold the fibres between them, and are fitted up with wheels at the end to run upon the frame, and thus advance or retreat at pleafure from the fpindles. It was not attempted with this machine to fpin a finifhed thread immediately from the lock of wool or cotton, but coarfe and loofe threads are previoufly prepared on the hand-wheel, which can be done with great rapidity, and the coppins or balls of thefe loofe threads are placed in the jenny, and conducted, firft between the clafps or rulers before mentioned, and then to the fpindles. By this means, when the carriage of the clafps is drawn backwards from the fpindles, the clafps being feparate, the threads draw between them from off the coppins, and at the fame time that portion of each thread which is between the clafps and the ends of the fpindles, receives its twift; but having drawn out a certain length of each thread in this manner, the clafps are fhut together; and the motion of the fpindles, as alfo the retreat of the clafps, is continued, by which means the threads are ftretched out to their intended finenefs, and being thus finifhed, the threads are wound upon the fpindles, by being brought oppofite to the middle p...

of the ſpindles by a rail of wood, called the *faller*, which moves upon centres, ſo as to deſcend horizontally before all the ſpindles, and depreſs all the threads together, ſo that they will wind up by the motion of the ſpindles, and as they wind, the claſps return towards the ſpindles. The operations are then again repeated, and thus continued, until the coppins or balls of thread, wound upon the ſpindles, acquire their proper ſize.

The next improvement in ſpinning-machines was the introduction of the ſlubbing-machine, or billy, for preparing the rovings for the jenny; an operation which was at firſt performed by the hand-wheel. This machine has ſimilar parts to the jenny, but they are differently arranged, to adapt it to ſpin the wool as it comes from the carding-machine, in the ſtate of cardings, which are locks of wool drawn out to about the ſize of candles, and from two to three feet in length. For this purpoſe the ſpindles are made to travel on the carriage, and the claſps ſtand ſtill, being the reverſe of the jenny. The cardings are laid upon an endleſs cloth, which revolves over two rollers, and lies in an inclined poſition at the end of the machine; and one carding is laid upon the cloth oppoſite to each ſpindle, the ends being pieced with freſh cardings by children, as faſt as the ſpindle works them up. A roller preſſes down upon the cardings, to hold them faſt upon the feeding-cloth, and to make them move with it; and juſt beyond this roller the claſps are fixed to hold the rovings, when the proper lengths are drawn out by the retreating of the ſpindles, which, as before ſtated, are ſituated in the carriage. The operation of the billy is the ſame as that of the jenny, *viz.* that the carriage is drawn out, and the feeding-cloth revolves over its roller to give out the cardings until a certain length: the claſp is then ſhut down, and the further extenſion of the threads is produced by ſtretching; which being done, the threads are wound upon the ſpindles.

The inventions of ſir Richard Arkwright ſoon ſuperſeded theſe machines. His principal invention in the ſpinning was the introduction of the rollers, to draw out or extend the fibres to their full length, which is by this means much more perfectly performed than by the fingers of the ſpinner. For the immediate twiſting of the thread, he adopted the ſpindle, bobbin, and flyer of the old flax-wheel, placed in a vertical poſition, but added to it the important improvement of raiſing and lowering the bobbin, to diſtribute the thread regularly and equally upon all the length of it, the ſame which we have before deſcribed as being applied by Mr. Antis to the common ſpinning-wheel. A full deſcription of this machine, which is called the water ſpinning-frame, will be found in the article *Cotton* MANUFACTURE, *Plate* IX. *Cotton Manufacture.*

The ſpinning-jenny was again introduced, and rendered equal, and for ſome purpoſes ſuperior, to the water-frame, by Mr. Crumpton, who combined with it the ſyſtem of rollers of ſir Richard Arkwright, and called it the mule. It is alſo fully deſcribed under *Plate* XI. *Cotton Manufacture.* See *Cotton* MANUFACTURE.

The great ſucceſs which attended the ſpinning of cotton by theſe machines, induced many perſons to attempt the ſpinning of flax and wool by ſimilar means. Short wool, for the manufacture of cloth, is ſpun by the billy and jenny; but flax and long wool for worſted require very different treatment from cotton and ſhort wool, particularly the flax, owing to the great length of the fibres, and to their being of ſuch irregular lengths: in conſequence, when they are extended by the rollers, on Arkwright's principle, ſome fibres will be broken, if the diſtances between the rollers is too ſmall; and on the other hand, if the diſtance is too great, the fibres will not be properly extended. The latter, however, is the leaſt evil of the two; and, in conſequence, the ſpinning-frames for flax have the rollers, between which the extenſion or drawing out is effected, placed at a diſtance of from 14 to 18 inches between the firſt two pair of rollers, through which the flax paſſes; the next two pair ſix or eight inches; after which it is paſſed between the third pair of rollers at a diſtance of five or ſix inches, and then delivered to the ſpindles, which are ſimilar to thoſe of the water-frame, but placed in an inclined poſition. The rollers are made in a very different manner from thoſe for cotton, being only narrow wheels juſt wide enough to receive the fibres of flax between them; and the fibres are prevented from getting out ſideways by ſmall tin ſpouts, through which the flax paſſes, as the rollers draw it forwards. The reaſon of this is, that the flinty ſurface of the flax would ſoon wear a hollow part round a plain roller, which would then let the flax ſlip through; but the narrow wheel wears down equally over the whole breadth of its edge. The lower pair of theſe rollers, or wheels, revolves in a ſmall trough of water, in the ſame manner as a grind-ſtone, and thus keeps the flax conſtantly wet, which is neceſſary, in order to ſoften the fibres, and make them ſpin into a firm and ſmooth thread.

Worſted is alſo ſpun in a frame reſembling the water-frame of Arkwright, from which it only differs in the relative diſtances of the rollers, by which the drawing out or extending of the fibres is effected.

Meſſrs. Clarke and Bugby obtained a patent in 1806, for improvements in a machine for ſpinning hemp and flax, which is intended to be worked by hand labour, and to be at ſuch a ſmall expence, as to bring it within the reach of ſmall manufacturers. The inventors ſtate it to be conſtructed upon ſuch ſafe and eaſy principles, that no length of experience is neceſſary to enable children to work it; and that it occupies ſo little ſpace, that the machines may be placed in ſmall rooms, out-buildings, or other cheap places. To effect the above purpoſes, it was neceſſary to get rid of the flyer fixed upon the ſpindle uſed in the old machinery for ſpinning hemp or flax, which additions require a power in proportion of five to one; and alſo to ſurmount the difficulty which ariſes from the want of elaſticity in theſe ſubſtances, and which prevents them from being ſpun, by ſtretching out at the ſame time that the thread is twiſted, in the manner of the mule or jenny.

Theſe patentees recommend a machine, which is in fact a mule with certain modifications; and to give the effect of elaſticity in the fibres, they have two methods. The moſt ſimple, and that which they particularly recommend, is to provide a holder of large wire for every ſpindle, which holders are ſeveral inches in length, fixed in an arbor or ſhaft, that extends from one end of the carriage to the other.

This arbor or ſhaft, with the holders, may be conſidered as an enlarged and improved ſubſtitute for what is called the faller in the mules or jennies for ſpinning cotton, and the wire-holders fixed therein have elliptical eyes at their extremities, through each of which a thread is conducted in its paſſage from the rollers which draw out the thread to its ſpindle. The wire of which the holder is made, after forming the elliptical eye, is left or extended beyond the uppermoſt part, ſomething in the manner of a cork-ſcrew, ſo that the yarn may be conveniently ſlipped in when occaſion may require it. Theſe holders for each thread are for the purpoſe of keeping the yarn in a ſtate nearly vertical over the tops of the ſpindle, when the carriage which contains them is coming out; and as they will readily yield or ſpring from the vertical poſition, they have the ſame effect as elaſticity

in the fibres of the ſubſtance which is to be ſtretched out; but the wires being removed from the vertical ſituation at the beginning of the return of the carriage, and thrown into nearly a horizontal poſition, by inclining the ſhaft into which they are all fixed, they bring the yarn below the tops of the bobbins or quills which are fixed upon the ſpindles, which will then wind up the threads upon them when the ſpindles are turned round, and then the wire-eyes being regularly curved, and raiſed up again by the motion of an elliptic wheel, which is turned round by the machine, they diſtribute the yarn regularly upon the bobbins or quills, and prevent it from hinkling, and improperly doubling or twiſting together. Another method of compenſating for the want of elaſticity in hemp and flax, is to fix a round bar of wood, about an inch and a half in diameter, the whole length of the carriage, about three or four inches above the tops of the ſpindles, ſo that the outer ſurface, or that next the perſon who works the machine, may be perpendicular, or nearly ſo, over the tops of the ſpindles, the inner ſide having pieces of wood or metal fixed or nailed thereto, leaving only ſmall ſpaces or notches between each, for the yarn to paſs through. The uſe of theſe pieces is to prevent the threads from getting together and entangling. Every thing relating to the wire-holders before mentioned, and the arbor to which they are affixed, muſt be applied in concert with theſe pieces of metal, which form a ſeparation between the threads.

The art of ſpinning, which nature has given to many animals of different kinds for their preſervation, and other purpoſes, is not confined to the inhabitants of the earth or air alone, but is even extended to thoſe of the ſea. M. Reaumur has ſhewn, by a ſeries of curious experiments, that the common muſcle, and ſome other ſhell-fiſh of the ſea, poſſeſs it in a great degree of perfection. See Muscle.

But he obſerves, that though the workmanſhip is the ſame, the manner of producing it is very different. Spiders, caterpillars, and the like, make threads of any length that they pleaſe, by making the viſcous liquor, of which they are formed, paſs through a fine perforation in the organ appointed for this ſpinning: but the way in which the muſcles form their threads is very different, as the former reſembles the work of the wire-drawer, ſo does this that of the founder, who caſts metals in a mould. The canal of the organ deſtined for the muſcle's ſpinning, which, from its ſhape, is commonly called its tongue, is the mould in which its thread is caſt, and gives it its determinate length. Mem. Acad. Par. 1711.

Spinning-*Wheel*, in *Rope-making*, for twelve ſpinners to ſpin yarn at the ſame time, is about five feet in diameter, and is hung between two poſts fixed in the ground: on its top is fixed a ſemi-circular frame, called the head, which contains twelve whirls, that turn on iron ſpindles, with hooks to their front ends to hang the hemp on, and are worked by means of a leather band encircling the wheel and whirls. The whirls are made to run with a truer motion when the head on the riſing ſide of the band has a larger ſegment of a circle than the falling ſide; or in other words, let the baſe part of the head be longer from the middle than the oppoſite or falling ſide, by which means the band will be kept equally tight over the whirls, and conſequently the motion be alike to all. N.B. Heads made in this manner have the wheel turned always the ſame way.

Spirits

Spirits, *Distilled*, a general name given among distillers to those ardent liquors that are obtained from various materials, and by different processes of distillation. The nature and properties of these liquors, and the modes of obtaining them, are detailed under the articles Alcohol, Brandy, Distillation, Fermentation, &c.; but we shall here specify some particulars that more immediately relate to the common spirituous liquors that are, we lament to say it, so much in use in our own country. These are, for the most part, prepared from fermented corn of one kind or other, with certain additions, at the pleasure of the distiller, of molasses, carrots, and other subsaccharine vegetables. The principal ingredient, except in a season of scarcity, is one kind or other of grain. (See Addition.) The spirit thus procured is rectified for sale by being redistilled with juniper-berries, turpentine, and other substances, in order to modify and improve its flavour and appearance. The grain, when barley is used, is usually first malted, and in Scotland it is dried with peat, which gives to the spirit distilled from it, called "whisky," its peculiar flavour. It is then ground into coarse powder, and the infusion fermented with yeast in large tuns. This fermented liquor is called "wash," and in this state it is fit for distillation. Under the articles already referred to, the general process and the implements used in it are described; but previously to the operation some substances are added to the wash, for the purpose either of increasing the quantity of spirit that is afforded by it, or of keeping down the essential oil derived from the malt, which would give the liquor a nauseous flavour, or of regulating the boiling within the still, and preventing it from boiling over or "running foul," or of neutralizing the acid generated during the fermentation, which would very considerably lessen the product of spirit. For these purposes soap is considered the best addition, and accordingly it is used in large quantities. Other distillers use alkalies. At the commencement of the operation, the liquid is oily and turbid, and has a nauseous flavour, on account of the oil of the malt which accompanies it; but by degrees it becomes clear, and runs so to the last, although its strength decreases, and it becomes more watery,

and consequently of less specific gravity. (See *Specific* GRAVITY.) The quantity intermediately obtained, omitting the first and the last products, is then redistilled or "rectified," (see RECTIFICATION); and in this stage of the operation, those additions (such as juniper-berries, &c.) which give the spirit its flavour, are introduced into it. The process of distillation on a small scale is simple and easily conducted; but the large distilleries, where expensive works are carried on, require a greater degree of practical skill, both in the preparation of the apparatus, the adjustment of the materials, and the conduct of the operation. In order to expedite the process, several alterations have been made in the form of the still, particularly in Scotland, where it is an object of importance to be quick in the dispatch of the operation, on account of the mode of levying the duty; and, therefore, by gradually widening the bottom and contracting the height of the still, distillation is performed with a surprising rapidity. A still is said to have been constructed, which contains only 40 gallons in the body and three in the head, and in the use of it the whole time of its operation, from its commencement to its close, amounts only to 2¾ minutes, when the charge of wash is 16 gallons, or ⅖ths of the whole content. In rectification, which is a slower process, the charge is 24 gallons, and the time of distilling about 10 minutes.

A good spirit may be obtained without malting the grain, whether it be barley, or any other kind of corn which will answer the purpose. With us, a mixture of barley and malt is generally preferred; in Holland, the very best geneva is made from wheat and malt, though more commonly from malt and rye, the latter yielding more spirit than wheat.

The following process is that which is practised by most distillers. A quantity of rye-flour, coarsely ground, is mixed with a third or fourth part of malt, and put into the fermenting tub, with cold water, stirring it well with the hand, to prevent the meal from clotting. Water of a blood-warmth is then added, in sufficient quantity, after which the ferment, composed of the yeast of former operations, dried and kept for a certain time, is mixed with the whole. (See FERMENT.) When the weather is favourable, and the heat well regulated, the fermentation begins in six hours, and terminates on the third day, when the liquor becomes transparent, and assumes a hot pungent taste. The distillation is then immediately commenced, before the liquor turns sour, which should as much as possible be avoided. The distillation is conducted very slowly, to prevent the impregnation of the oil of the grain with the spirit, and of course the unpleasant flavour of the spirits. The first spirit is then rectified by a second distillation over juniper-berries, or in "double geneva," by a third process.

In some of the ordinary sorts, however, the juniper-berries are mixed with the fermenting materials, and one distillation suffices. In the common geneva or gin, vulgarly used in this country, the fine juniper flavour is coarsely imitated by turpentine. See GENEVA.

For the process of obtaining arrack, brandy, and rum, see ARAC, BRANDY, and RUM.

SPIRITS, *Proof*, or *common saleable goods*, are spirits of any kind of a determinate strength, being the same with those of good brandy, and the malt and sugar spirits of the distillery, as they are usually sold; containing equal quantities, or definite proportions, of rectified spirit and water.

The best proof spirit is that distilled from French wine; but for common use, the spirit drawn from molasses may be employed.

The common method of examining whether spirits have this due degree of strength is this:—take a long phial, fill it half way with the common malt spirit, and give it a smart stroke by its bottom against the palm of the hand, there will then appear on the surface a chaplet, or crown of bubbles, which will go off again in a strong manner; that is, first remaining a while, and then going off by degrees, without breaking into smaller bubbles, or swelling into larger.

By this experiment all the traders in spirits judge of the strength of the goods they purchase; yet this is a mere fallacy and deception; for if only a little vinous or saccharine matter, as treacle, syrup, must, rob of fruits, or the like, be added to a quantity of highly rectified spirit of wine, this slight addition will give a brandy proof to that spirit. See ALCOHOL, BRANDY, and BEAD *Proof*.

Whether there be any secret for making weaker spirits shew this proof as well as brandies, &c. is not certainly known; but the thing is practicable, since arrack, which is but of half the strength of brandy, gives as fair a proof this way; and if a drop or two of any essential oil be added to a pint of brandy, it takes off its proof, and makes it appear much weaker than it is. The true strength may, however, always be known, by carefully burning away a measured quantity of brandy, &c. since if it leaves one half water it is right; if more or less, it is too strong, or too weak.

But beside the false method of judging of brandies by what is called *proof*, there is another not less fallacious one of judging of their goodness, though kept as a great secret in the hands of some dealers, and imagined a certain criterion to determine whether foreign brandies are mixed with corn spirits. These distillers are provided with a certain yellow liquor, a few drops of which being poured into a glass of right French brandy gives it a beautiful blue colour, and, by the strength and goodness of this colour, they judge and buy; but if common malt spirit be tinged with oak, it would give this colour equally with French brandy, and might be purchased as such. This proof tincture is expeditiously made, by dissolving a little green vitriol, first calcined to a redness, in a weak spirit of sea-salt, which thus becomes a yellow liquor, a single drop or two of which being added to a glass of any inflammable spirit, coloured yellow or brown with oak, or with long remaining in the cask, will instantly turn it of a bright and beautiful blue.

The best way of judging in these cases is by the nose and palate. Dilute a quantity of brandy considerably with water, and you will perceive the malt taste, if mixed with malt spirits; or burn a little in a spoon, and by the smell and taste of the water it leaves, you will easily judge whether there be malt in it.

Proof spirits may be distinguished into three kinds, *perfect proof*, *more than perfect proof*, and *less than perfect proof*. By *perfect proof* is usually understood that crown of bubbles, before mentioned, of a certain size, arising as a head upon a small quantity of a well-qualified spirit shook in a slender phial.

Proof more than perfect, is that in which the bubbles raised by shaking the spirits, are larger than those on the common or perfect proof, and go off more suddenly; that is, according as the spirit is higher, or approaches more to the nature of rectified spirit, or, as it is usually called, *spirit of wine*.

Proof less than perfect, is that in which the bubbles are smaller, and go off quicker and fainter than in perfect proof; the spirit in this case being mixed with more than its own quantity of phlegm, or being too poor for sale.

The surest method of judging of the strength of spirits, is by the hydrometer, water-poise, or balance; or, 2dly, by distillation, or finally, by deflagration. The specific gravity of totally inflammable spirit is so much less than that of

phlegm, or common water, that it is eafily fenfible upon the balance; whence an exact hydrometer, well balanced and graduated, and furnifhed with a proper fcale of weights, may be of great ufe to affign the proportions in which pure fpirit and water are mixed in any given liquor. (See *Specific* Gravity, and Hydrometer.) Though, perhaps, a readier way than this may be that of M. Homberg's, mentioned in the Memoirs of the Paris Academy, 1718, for determining the different gravities of different fluids, by means of a bottle with a very long and flender neck; which being filled to a certain height with any mixture of fpirit, is weighed againft the fame bottle filled with pure water.

The moft exact of all methods of determining the ftrength and fpirit is by diftillation, rectifying it up to an alcohol, or totally inflammable fpirit; but this, though liable to no error, is too tedious to come into common ufe. And, upon the whole, the beft method of all others, feems to be that of deflagration, which M. Geoffroy has been at much pains to adjuft and improve.

In commerce, with regard to fpirits, it would certainly be a much better method to abolifh fuch uncertain proofs, and to make all the goods of the ftrength of what we call fpirits of wine; that is, a totally inflammable fpirit, whofe purity is much greater, whofe ftrength may always be found out with exactnefs, and whofe bulk, ftowage, carriage, and incumbrance, would be only half in regard to that of brandy, or proof fpirits; and it might at all times, as occafion called for it, be mixed into a great variety of extemporaneous liquors, and the exact degree of ftrength would be always precifely known.

This operation, indeed, in the common way, proves fo tedious and expenfive, and, after all, fo fhort of expectation, and fo generally unfatisfactory, that it is not to be expected that the common diftillers, till they have fallen into a better manner of working, fhould come into the propofal. But if, inftead of the common way of rectifying by the hot-ftill, they would try the ufe of a large balneum Mariæ, made of a large rectangular boiler, and a fet of tall conical veffels, they will find that little fire, and little attendance, and confequently very little expence, will, in this manner, furnifh them with fpirits reduced at once to this ftandard, and greatly fuperior, in all refpects, to the common ones of the fame ftrength. In this cafe there would be no need of any addition of falts; but the diftiller may work more perfectly, and more expeditioufly without them, and thus preferve the fine effential vinofity of the fpirit, which, in the common way of working, they conftantly lofe.

The advantage of this method would be yet greater to the apothecaries, and the makers of compound cordial waters, who want only a pure fpirit of fuch a ftrength, and fuffer greatly in the finenefs and perfection of their commodities, by the fpirit they are obliged to ufe having in it a fulfome and naufeous oil of its own, which will always mix itfelf with their compofitions, and the oils of the aromatics, &c. which they add to it. If fpirits were brought to this ftandard for the market, there would be no poffibility of deceit, and no farther examination need be made of it by the buyer than its burning perfectly dry in a fpoon. Shaw's Effay on Diftillery.

It is, however, to be obferved, that though the burning of fpirits away in a fpoon may ferve the trader in the common way, yet M. Geoffroy has obferved, that they are no proofs for the philofopher, or the chemift, being not at all determinate or exact, though commonly fuppofed fo.

From what has been faid, it appears that brandy is much more inflammable than wine, and fpirit of wine much more fo than brandy, and ought to burn away without leaving any remainder. Hence it is vulgarly fuppofed, that fuch fpirit of wine as burns wholly away contains no phlegm, and that if two parcels of fpirit both burn wholly away in this manner, they muft be the fame in ftrength, and in all other qualities; but M. Geoffroy has proved by experiment, that fuch fpirit as burns wholly away, does yet contain a great deal of water, and two parcels both may burn thus away, and yet be very different; and that this trial is not determined by the entire abfence of the phlegm, but by its proportion to the oil.

If the fame fpirit of wine, which in the common way of burning leaves no water, be again tried, by burning it in a hollow veffel fet to float in a large quantity of cold water, it will then leave a confiderable quantity of water; nay, all that is rectified only in the common way, leaves a large portion of phlegm on this experiment. The plain reafon of which is, that this is the only fair trial, the other in the common way being fallacious. In this there is no more water left than was in the fpirit; but in the other, the veffel becoming heated by the burning of the fpirit, that heat gradually evaporates the water, as the fpirit burns away; fo that the one is as foon gone as the other. But keeping the veffel cool by external water, prevents that evaporation, and confequently retains and difcovers all that cannot burn of the fpirit.

The quantity of water thus difcovered in fpirit of wine is very great, and it has always been found, that in proportion as the experiment has been made more and more perfect, the fpirit has always appeared proportionably lefs and lefs fo.

Pure alcohol, or alcohol of a fpecific gravity of .796, at 60° Fah., which is the ftrongeft that can be procured, leaves no water; rectified fpirit of moderate ftrength, 25 *per cent.*; French brandy, 56; and common malt liquor, 65.

The teft for afcertaining the ftrength of fpirits by pouring a few drops on gunpowder, is very incorrect. A more accurate teft than any of thefe, and fufficient for common purpofes, is to fhake the fpirit in a phial with very dry carbonate of potafs, and obferve the quantity of water attracted by the alkali, which indicates its ftrength. But the only certain mode of afcertaining the relative ftrength of fpirits, is by determining the fpecific gravity of the fpirit at a given temperature; thus, at 60° Fahr. the fpecific gravity of rectified fpirit is .83599, at 65° it is .83362, and at 70° the gravity of the fame fpirit is .83134; while the gravity of the proof fpirit of the London College, at the fame degree of temperature, is .93002, .92794, and .92580, (fee the table under Spirits, in the *Materia Medica*,) the weakeft fpirit having the greateft fpecific gravity, and this diminifhing as the temperature increafes. For ordinary purpofes, the relative ftrength of fpirits may be known by weighing the fample to be tried in a phial capable of holding exactly 500 grains of water. An equal bulk of rectified fpirit weighs 418 grains, and of proof fpirit 465; hence the number of grains above or below thefe fums will indicate the relative ftrength of the fpirit.

The quality of the phlegm that is left is alfo of ufe to judge of the fpirit by; if that were perfectly fine, this ought to be perfectly limpid and clear, and without tafte or fmell: as it wants either of thefe properties, it is a proof of the want of perfection of the fpirit it is obtained from; but the greateft of all defects, is its having a coarfe oil fwimming upon it, and giving the colours of the rainbow in different lights. Mem. Acad. Par. 1718. See Brandy.

Spirits, *Colouring of*, the art of giving to diftilled liquors a colour, which takes off their watery appearance, and gives them a refemblance of the foreign brandies, &c.

The colouring is not only neceſſary on this account, but as we uſually eſteem the ſpirits by the proof of the crown of bubbles, it is found that the clean rectified ſpirit will not afford this proof till it has received its doſe of the colour The diſtillers diſpenſe this colour in any proportion that they find convenient or neceſſary; it is always yellow, but, according to the degree, differs extremely in deepneſs, from the paleſt ſtraw-colour to the deepeſt orange. This art of colouring was firſt introduced, from obſerving that all the fine and ſoft foreign brandies, that had the mellowneſs neceſſary to their perfection to the taſte, had alſo a yellow colour. The colour, in this caſe, has indeed nothing to do with the flavour; but that being kept in caſks the ſame age that was neceſſary to give them this mellowneſs, would alſo give them a colour from the wood. It was hence ſuppoſed, that the particular excellence of the foreign brandies depended on the woody colour, and accordingly pains have been taken to give the ſame colour to our ſpirits by various methods.

The way of obtaining it, by many years ſtanding in the caſk, proved too tedious for our haſty workmen, and accordingly they provided means of giving it extempore by ſtrong tinctures of ſeveral ingredients; the chief of which are logwood, ſaffron, Japan earth, treacle, burnt ſugar, and oak-chips; the three former of theſe have but little to recommend them, but the others are found very ready, and very proper for the uſe.

Treacle gives a fine colour not much unlike that of the foreign brandies, and being neceſſarily uſed in a large quantity, as its colour is but dilute, it not only mends the bubble, or bead-proof, impaired by the rectification, but alſo gives it a fulneſs in the mouth; both which properties are very agreeable to the vulgar, who are the chief retail conſumers of theſe coarſe goods.

Burnt ſugar, that is, ſugar diſſolved in a little water, and ſcorched over the fire till it turns black, goes much farther in the colouring than treacle, and at the ſame time gives no ſweetneſs, but rather an agreeable bitterneſs; and thus recommends itſelf to the nicer palates, that are not for a luſcious ſpirit. Indeed ſugar, thus treated, tinges to a great perfection, and that without loſs of time, and with as much cheapneſs as can well be deſired.

The laſt article mentioned, namely oak-chips, is of all others the moſt natural for imitating the dye of foreign ſpirits, as it is the very wood of which the caſks they come over in are made, and from which they take that colour of which we are ſo fond. The colouring with oak has alſo this farther advantage in ſpirits meant as ſophiſtications of the foreign ones, that it will ſtand ſome teſts uſually had recourſe to on the occaſion, which the others will not ſtand.

Common ſpirit poured on oak-chips, and digeſted in a moderate heat, eaſily fetches out the reſinous part of the wood on which the colouring depends; but then it does not go near ſo far as the burnt ſugar; a large quantity of oak being required to colour a ſmall parcel of brandy, or ſpirits. It is adviſeable not to make the tincture every time, but to have recourſe to an extract of this wood in a liquid form: this extract is beſt made in two menſtruums, alcohol and water, and may be evaporated to any ſtrength, ſo that a very ſmall doſe of it will tinge a great quantity of liquor. The two liquid extracts will be mixed together, and as they will be apt to ſeparate in ſtanding, it will be proper to add to them, when newly made, a quantity of fine ſugar; this will give a body to the whole, and it will keep better from mouldineſs than it would without it. Shaw's Eſſay on Diſtillery.

Spirits, *Convertibility of*. This is a doctrine that has obtained among many of the moſt curious experimenters, and, indeed, the moſt intelligent of our chemiſts have always allowed, that provided proper care were taken in the getting together of the material, one ſpirit may always be changed into another, as brandy into rum, malt-ſpirit into brandy, and brandy into malt-ſpirit. The principles on which this is believed are theſe.

All ſimple ſpirits (as they are called) conſiſt of four parts, water, oil, phlegm, and alcohol; the laſt of theſe is the eſſential part, and is what conſtitutes the whole a ſpirit. In reducing ſpirits, therefore, to their utmoſt degree of ſimplicity and purity, it is evident that the three ſuperfluous parts are to be got rid of, and the fourth left alone; by this means the alcohol is procured diſtinct, and is a liquor *ſui generis* of many peculiar qualities, not to be found in any other fluid.

Among others, it has theſe remarkable properties: 1. When abſolutely purified, it is an uniform and homogene liquor, capable of no farther ſeparation, without loſs or deſtruction of ſome of its homogeneous parts. 2. It is totally inflammable, leaving no ſoot nor any moiſture behind. 3. It has no peculiar taſte or flavour, any more than pure water, except what is owing to its nature as alcohol, or perfectly pure ſpirit. 4. It is an unctuous and criſpy fluid, running veiny in the diſtillation, and its drops rolling on the ſurface of any other fluid, like peaſe upon a table, before they unite. 5. It appears to be the eſſential oil of the body it is obtained from, broken very fine, and intimately and ſtrongly mixed with an aqueous fluid, which is aſſimilated, or changed in its nature in the operation. 6. And laſtly, it ſeems to be a kind of univerſal fluid, producible with the ſame properties from every vegetable ſubject; but to produce it thus requires ſome care in the operation. See Alcohol.

On theſe principles is founded the opinion, that all ſpirits may be reduced to a perfect ſimilarity, or ſameneſs, from whatever ſubject they were procured, and on this depends their convertibility into one another; for when once they are brought to this ſtandard of ſimplicity, there needs nothing more than to add the oil of ſuch of the finer ſpirits as is required to convert the ſpirit into that particular kind. By this means the ſame taſteleſs ſpirit, whether obtained from malt, ſugar, or grapes, may be made either into malt-ſpirit, brandy, or rum, by adding the eſſential oil of the grape, ſugar, or malt; and thus, what was once malt-ſpirit, ſhall become brandy, or whatever elſe the operator pleaſes.

Many methods have been attempted to obtain the firſt point, that is, the reducing of the ſpirit to perfect and pure alcohol. The moſt practicable means ſeem to be long digeſtion, and the repeated diſtillation from water into water, where the eſſential oil will at once be left upon two ſurfaces, and the acid imbibed. The ſhorter ways are thoſe by rectifying from neutral abſorbent ſalts and earths; ſuch as ſugar, chalk, and the like. And laſtly, the uſe of fixed alkalies may be tried, for theſe very forcibly keep down both the phlegm and oil; inſomuch that this laſt method promiſes to be the ſhorteſt of all, if the art were known of utterly aboliſhing the alkaline flavour, which the alcohol is apt to acquire in this operation, and which, for this purpoſe, is by no means ſuitable, as abſolutely deſtroying all vinoſity, which univerſally conſiſts in a fine volatile pungent acidity. The diſtillers are the only people whoſe buſineſs would lead them to make the experiment. This method of converting one ſpirit into another, would be of immenſe

profit to them if they could perfectly succeed in it; but as it would require time and slow processes to bring it about, there is but little hope of its ever being brought to bear among them, while they are in their present scheme of doing every thing with dispatch and hurry.

Dr. Shaw has said a vast deal in the praise of a tasteless spirit, which is producible from a vegetable substance, only overlooked, as he tells us, because it is too common, with which all the foreign spirits might be imitated to the utmost perfection by means of their essential oils, all thin fine wines raised to any due degree of strength, without giving them the brandy flavour, and many other things of great use performed; but he has not told us what the vegetable substance is from which we are to obtain this. Shaw's Essay on Distillery.

SPIRIT, *Ardent*, called also *spirit of wine*, because it can only be obtained from substances which have undergone the vinous fermentation, is a very light, very volatile, very fluid liquor, perfectly white and limpid, and of a strong, penetrating, agreeable taste and smell. See ALCOHOL.

Spirits drawn from wine, such as French brandy, may, in a great measure, be purified or rectified by simple distillation, in tall vessels with a gentle heat, the pure spirituous parts rising before the phlegm: if French brandy be thus distilled to one-half, the distilled spirit proves tolerably pure. See BRANDY.

But wine or brandy being in this country too dear an article for distillation, this purification is chiefly practised on the cheaper spirits of molosses and malt-liquors. To separate the offensive oil with which these abound, after they have been freed by distillation from the greatest part of their phlegm, they are mixed with an equal quantity of spring-water, and the spirit drawn off again by a gentle heat: a considerable portion of the oil is thus left behind in the water, which now proves turbid and milky, and very nauseous both in smell and taste. The first produce is the strongest and purest, and when it has come over to the amount of $\frac{1}{4}$th of the whole contents of the still, forms the rectified spirit. By repeating this ablution with fresh quantities of water, the foulest and most offensive spirits may be purified from all ill flavour. To complete the purification, or free them from their remaining phlegm or oil, or the watery vapour which is raised even by the gentlest heat in which they can be distilled, a little fixed alkaline salt, thoroughly dried and powdered, or lime, or some other article of a like kind, is added; which, imbibing the phlegm, is thereby dissolved into a ponderous liquid, that does not mingle with the spirit, but settles at the bottom. If the spirit is very phlegmatic, four pints will require a pound of the alkali; if the distillation has been performed with due care, half this quantity, or less, will be sufficient: in either case, if all the salt dissolves, the spirit is to be digested with a little more, till at least a part remains undissolved. The spirit now poured off is to be again distilled, in order to separate from it a portion of the salt which has united with it, and which, though extremely minute, may in some respects change its qualities. As some particles of the alkali are apt to be carried up with it, even in the distillation, so as to communicate an ill flavour, or an urinous taste, it is adviseable previously to add a small portion of calcined vitriol, or burnt alum and charcoal, which will completely absorb the alkali, without giving any new impregnation to the spirit. Malt-spirits, when properly rectified, yield as pure and as strong rectified spirit as brandy. Lewis's Mat. Med. See DISTILLATION, and SPIRITS, in the *Materia Medica*, infra.

When only a small quantity of spirit of wine is to be rectified, the usual operation for this purpose, by means of distillations of the spirit called aqua vitæ, obtained from the first distillations of liquors that have undergone the spirituous fermentation, and which are overcharged with a large quantity of phlegm and light oil, is difficult. These distillations being slowly conducted with a gentle fire and water-bath, yield but a small quantity of that liquor, which, being the most volatile, rises first with the least heat, and which is the true or rectified spirit of wine. Several chemists, therefore, in order to obtain a larger quantity of the first spirit, propose to mix with the spirit of wine some intermediate substances, to absorb and retain its phlegm and oil, such as dried and calcined salts, very dry chalk, &c. Kunckel proposes to separate more effectually the oil, by adding to the spirit a large quantity of water, and by distilling this diluted spirit with a very gentle heat. But the trouble and inconvenience of depriving the spirit of wine of the water with which it was diluted in this process, may be avoided, by rectifying at once a large quantity of aqua vitæ. Nothing more is required to obtain at once a considerable quantity of pure spirit of wine, than to set aside the twelve or fifteen pints first drawn over from a large quantity, *e. g.* from three hundred pints of aqua vitæ, distilled with a very gentle fire in a large alembic. As the most spirituous, least aqueous, and least oily part of it always rises first, these twelve or fifteen pints are perfectly rectified spirit of wine, especially when the heat has been well conducted.

By thus keeping apart portions of the spirit obtained, at different times, we may have spirit of wine of the several degrees of strength and purity. The weaker spirit may, by another distillation, be again rectified; and the spirit of moderate strength may be preserved for many uses. The method is followed by M. Beaumé in the rectification of spirit of wine, and is certainly the most convenient and the best.

A perfectly rectified spirit of wine, or such as is entirely freed from water, is undoubtedly a thing of frequent and necessary use in the nice operations of chemistry.

It had used to be prepared, either by often distilling the spirit, and every time drawing over only half of it, and repeating this till the half remaining in the cucurbit appeared as strong as that drawn over; or else by raising it to a great height from the body of the vessel, and this in a very gentle heat, so that spirit alone could rise, the water not being capable of being driven so far by that degree of heat.

But the accurate Boerhaave always found upon trial, that there was still remaining some water in these spirits, whether prepared by the first or second process, or both. Boerhaave's Chem. part ii. p. 124.

The method he therefore invented is this: fill a still half full of the spirit prepared for alcohol in one or other of these ways, and add to it half a pound of pure decrepitated, and perfectly dried sea-salt; put this in hot, then place on the head, and carefully lute the junctures; leave this for twelve hours in a heat so small, as not to make the alcohol boil, then distil off the spirit; keep the first two ounces apart, because some aqueous vapour may have happened to lodge in the head or worm of the still, which this certainly washes off; after this receive two-thirds of the following alcohol into a pure dry glass vessel, and keep it perfectly stopped; then draw off the remainder, and keep that by itself: there will remain a moist salt in the still, which has attracted the aqueous matter of the alcohol, and held it so down, that it could not rise by the heat of boiling water,

which is all that muſt be uſed in this diſtillation; and the ſalt having been firſt decrepitated, never makes any change in the alcohol by adding any thing to it. By this means an alcohol is prepared perfectly pure, and fit for all the uſes of chemiſtry.

For the teſts and properties of pure alcohol, ſee ALCOHOL.

M. Reaumur diſcovered, that a mixture of ſpirit of wine and water acquired a ſpecific gravity greater than that which would arithmetically reſult from the proportions employed of each of theſe liquors. Thus, fifty meaſures of ſpirit of wine, and fifty meaſures of water, mixed together, were found to make only ninety-eight meaſures; but in what progreſſion the denſity is increaſed by mixing various proportions of the two liquors, had not been determined till M. Briſſon made a ſet of experiments with that view; an account of which is given in the Memoirs of the Academy of Sciences of Paris, for the year 1769.

From his experiments he has conſtructed the following table, which ſhews this progreſſion, and alſo enables us to diſcover the proportion of ſpirit of wine and water, in any given mixture of theſe (as brandies, rums, &c.), the ſpecific gravity of which is found to correſpond with any of the ſpecific gravities in the table. Thus, for inſtance, if we find upon accurate trial, that the ſpecific gravity of the rum, brandy, or other mixture, whoſe ſtrength is required to be known, be to that of water as $942\frac{1}{2}$ to 1000, we learn, by inſpection of the table, that this ſpirituous mixture conſiſts of equal parts of water and ſpirit of wine, of which ſpirit the ſtrength is ſuch, that its denſity is to that of the water as 837 to 1000. The firſt column ſhews the proportion of well rectified ſpirit of wine in the mixture; the ſecond column ſhews the proportion of the water in the mixture; the third column ſhews the ſpecific gravity of the mixture; the fourth column ſhews the difference between the ſpecific gravity of the mixture and that of the preceding mixture; and the fifth column ſhews the proportion which the ſeveral augmentations of denſity, cauſed by penetration of the two liquors, have to each other, that is their progreſſion.

Spirit of Wine.	Water.	Specific Gravity.	Differences.	Proportionable Augmentations of Denſity from Penetration.
Parts.	Parts.			
16	0	837	0	0
15	1	$852\frac{1}{2}$	$15\frac{1}{2}$	$4\frac{51}{128}$
14	2	$867\frac{1}{3}$	$14\frac{5}{6}$	$8\frac{93}{128}$
13	3	$881\frac{1}{3}$	14	$11\frac{11}{128}$
12	4	$894\frac{1}{2}$	$13\frac{1}{6}$	$13\frac{108}{128}$
11	5	$907\frac{1}{3}$	$12\frac{5}{6}$	$15\frac{127}{128}$
10	6	$919\frac{2}{3}$	$12\frac{1}{3}$	$17\frac{98}{128}$
9	7	$931\frac{2}{3}$	12	$19\frac{21}{128}$
8	8	$942\frac{1}{2}$	$10\frac{5}{6}$	$19\frac{104}{128}$
7	9	$951\frac{2}{3}$	$9\frac{1}{6}$	$18\frac{123}{128}$
6	10	$959\frac{2}{3}$	8	$17\frac{14}{128}$
5	11	$967\frac{1}{3}$	$7\frac{2}{3}$	$15\frac{1}{128}$
4	12	$973\frac{1}{6}$	$5\frac{5}{6}$	$11\frac{68}{128}$
3	13	979	$5\frac{5}{6}$	$7\frac{110}{128}$
2	14	985	6	$4\frac{74}{128}$
1	15	$991\frac{1}{4}$	$6\frac{1}{4}$	$1\frac{93}{128}$
0	16	1000	$8\frac{3}{4}$	0

Spirit of wine is uſed in dyeing, as a non-colouring drug, and though it gives no colour itſelf, it ſerves to prepare the ſtuffs to receive other colours. Its conſumption is alſo very conſiderable in ſeveral other works and manufactures, particularly the making of varniſh.

Proof-ſpirit cannot be uſed for burning in lamps, for diſſolving reſins, and for making varniſh; and there is alſo a great number of tinctures, ſolutions, and mixtures, for which it cannot ſerve; but rectified ſpirit, or alcohol, beſides its ready uſe for medicinal purpoſes, may, when the ſpirit is of a proper kind, be made into punch, and all other mixtures, with greater purity, and much greater certainty and exactneſs in point of ſtrength. See next article and ALCOHOL.

SPIRITS, in the *Materia Medica*, "rectified ſpirit" of the London Pharmacopeia; "alcohol," "ſpiritus vinoſus rectificatus ſive puriſſimus," Edinb.; "ſpiritus vinoſus rectificatus," Dub.; is alcohol nearly in the higheſt ſtate of concentration in which it can be eaſily prepared in the large way for the purpoſes of trade. The London and Edinburgh colleges ſtate its ſpecific gravity to be to that of water as 835 to 1000, while the Dublin college ſtates it at 840. The Edinburgh college names this ſpirit alcohol; but directions being given both by the London and Dublin colleges, for the preparation of a ſtill ſtronger ſpirit, the name of alcohol, in their pharmacopeias, is judiciouſly retained for the ſtronger ſpirit, while that of rectified ſpirit is applied to the preſent preparation.

The alcohol of the Lond. Ph. is prepared by taking of rectified ſpirit a gallon, and of ſubcarbonate of potaſs, three pounds: add a pound of the ſubcarbonate, previouſly heated to 300 degrees, to the ſpirit, and macerate for 24 hours, frequently ſhaking the mixture; then pour off the ſpirit, and add the remainder of the ſubcarbonate, heated to the ſame degree; and laſtly, diſtil the alcohol from a water-bath, and preſerve it in a well-cloſed veſſel. The ſpecific gravity of this alcohol is to that of diſtilled water as .315 to 1,000.

The alcohol of the Dub. Ph. is prepared by taking of rectified ſpirit of wine, a gallon; pearl-aſhes, dried at a heat of 300°, and ſtill hot, a pound; cauſtic kali, in powder, an ounce; muriate of lime, dried, half a pound. Mix the ſpirit and the kali; add the pearl-aſhes, previouſly reduced to powder, and digeſt the mixture for three days in a cloſed veſſel, frequently ſhaking it; then pour off the ſpirit; mix with it the muriate of lime; and laſtly, diſtil with a moderate heat, until the reſidue begins to thicken. The ſpecific gravity of this ſpirit is to that of diſtilled water as 315 to 1000.

Rectified ſpirit of the ſpecific gravity of 835, contains about 15 *per cent.* of water; and to free it from this is the intention of the above proceſſes. The Edinburgh college has no proceſs for the preparation of pure alcohol, which may be eaſily diſpenſed with; but it has very improperly given this title to the rectified ſpirit of the other pharmacopeias. The theory of the operation is ſufficiently obvious. The affinity of the alkali and the muriate of lime for water is much greater than that of the ſpirit: it is, therefore, attracted by theſe ſubſtances, and prevented from riſing with the ſpirit during the diſtillation, by which means the alcohol comes over in a very highly concentrated ſtate. *Of the two* proceſſes, that of the Dublin college is to be preferred; muriate of lime being a much more powerful agent for ſeparating the water, which is the object in both, than ſubcarbonate of potaſs.

Dr. Black thus obtained alcohol of the ſp. gr. of 800°, and Richter procured it ſo low as 0.792, in the temperature of 68° Fahr. at which degree of concentration it may be regarded almoſt as pure alcohol, or alcohol perfectly free from water. That of the pharmacopeias is not free from water, though more than ſufficiently concentrated for all the purpoſes of pharmacy.

The following Table, drawn up by Lowitz, with an additional column by Dr. Thomſon, ſhews the ſpecific gravity of different mixtures of pure alcohol, of a ſpecific gravity .791, and diſtilled water, at the temperatures of 60° and 68° of Fahrenheit.

100 Parts by Weight.		Sp. Gravity.		100 Parts by Weight.		Sp. Gravity.	
Alcohol.	Water.	At 68°.	At 60°.	Alcohol.	Water.	At 68°.	At 60°.
100	—	791	796	49	51	917	920
99	1	794	798	48	52	919	922
98	2	797	801	47	53	921	924
97	3	800	804	46	54	923	926
96	4	803	807	45	55	925	928
95	5	805	809	44	56	927	§930
94	6	808	812	43	57	930	933
93	7	811	*815	42	58	932	‖935
92	8	813	817	41	59	934	937
91	9	816	820	40	60	936	939
90	10	818	822	39	61	938	941
89	11	821	825	38	62	940	943
88	12	823	827	37	63	942	945
87	13	826	830	36	64	944	947
86	14	828	832	35	65	946	949
85	15	831	†835	34	66	948	951
84	16	834	838	33	67	950	953
83	17	836	‡840	32	68	952	955
82	18	839	843	31	69	954	957
81	19	842	846	30	70	956	958
80	20	844	848	29	71	957	960
79	21	847	851	28	72	959	962
78	22	849	853	27	73	961	963
77	23	851	855	26	74	963	965
76	24	853	857	25	75	965	967
75	25	856	860	24	76	966	968
74	26	859	863	23	77	968	970
73	27	861	865	22	78	970	972
72	28	863	867	21	79	971	973
71	29	866	870	20	80	973	974
70	30	868	871	19	81	974	975
69	31	870	874	18	82	976	
68	32	872	875	17	83	977	
67	33	875	879	16	84	978	
66	34	877	880	15	85	980	
65	35	880	883	14	86	981	
64	36	882	886	13	87	983	
63	37	885	889	12	88	985	
62	38	887	891	11	89	986	
61	39	889	893	10	90	987	
60	40	892	896	9	91	988	
59	41	894	898	8	92	989	
58	42	896	900	7	93	991	
57	43	899	903	6	94	992	
56	44	901	904	5	95	994	
55	45	903	906	4	96	995	
54	46	905	908	3	97	997	
53	47	907	910	2	98	998	
52	48	909	912	1	99	999	
51	49	912	915	—	100	1000	
50	50	914	917				

* Alcohol of the London and the Dublin Pharmacopœias. † Ditto (Edinburgh); rectified ſpirit (London). ‡ Rectified ſpirit (Dublin). § Proof ſpirit (Lond. Dub.) ‖ Ditto (Edinburgh).

In the extract from Mr. Gilpin's table (ſee *Specific* Gravity), the ſtandard ſpirit was of the ſpecific gravity of 0.825, or contained 89 pure alcohol, and 11 water, in 100 parts.

Pure rectified ſpirit has a fragrant odour, and a hot highly pungent taſte. It is colourleſs; always fluid; cannot be congealed at any known degree of cold; evaporates ſpeedily at the ordinary temperature of the atmoſphere; boils at 163° Fahrenheit; and is extremely inflammable, burning with a blue lambent flame, without any ſenſible ſmoke. Like alcohol, it combines with water in every proportion; and, on account of its affinity for water, precipitates many of the neutral ſalts from their aqueous ſolutions. It is capable of diſſolving many ſaline bodies, and is the proper ſolvent of the greater number of the proximate principles of vegetables. Its conſtituents are 85 of pure alcohol and 15 of water, in 100 parts, when its ſpecific gravity is 835, at a temperature of 60° of Fahrenheit; but 83 only of pure alcohol, and 17 of water, when it is 840, as deſignated by the Dublin college.

Rectified ſpirit is a very powerful ſtimulant. In its undiluted ſtate it is never exhibited as a remedy; and is merely employed for forming the diluted ſpirit, and as a pharmaceutical agent.

The "ſpiritus tenuior," or "weaker ſpirit," of the Lond. Ph.; the "diluted alcohol," the "ſpiritus vinoſus tenuior ſive dilutus" of Edinb. Ph.; and "ſpiritus vinoſus tenuior" of Dub. Ph., or "proof ſpirit," is merely rectified ſpirit diluted with a certain proportion of water. According to the London and Dublin colleges, its ſpecific gravity ſhould be to that of diſtilled water, as 930 to 1000; while the Edinburgh college orders it of the gravity of 935. The former may be formed by mixing four parts by meaſure of rectified ſpirit with three of water, and contains 44 parts of pure alcohol, and 55 of water, in 100 parts; the latter is obtained from equal parts of rectified ſpirit and water, and contains 42 of pure alcohol, and 58 of water, in 100 parts. Alcohol, diluted to the degree of proof-ſpirit, is ſtill a very powerful diffuſible ſtimulant, and too ſtrong for internal uſe. Externally applied, it is recommended in burns; to reſtrain bleeding in paſſive hæmorrhagies; and as a friction or fomentation to relieve muſcular pains; and in a more diluted ſtate it forms a good collyrium in the latter ſtage of ophthalmia. Proof-ſpirit diluted with water is employed as a remedy in the form of tinctures and ſpirits; and the ardent ſpirits in common uſe may be regarded as nearly of the ſame nature. Theſe taken in moderation, increaſe the general excitement, communicate additional energy to the muſcular fibres, ſtrengthen the ſtomach, and exhilarate the mind. Hence they are often and advantageouſly uſed in caſes of debility and low typhoid fevers, in which the uſe of wine is indicated; and in habits diſpoſed to create acidity, they are even preferable to wine; ſome of them, particularly brandy, proving gratefully ſtomachic, when wine is nauſeated and rejected. As an article, however, of daily or dietetical uſe, particularly if taken in immoderate doſes, or long continued, ardent ſpirits, beſides being the ſource of much moral evil, and debaſing the human character nearly to a level with that of brutes, are apt to occaſion diſeaſe, and are commonly the origin of dyſpepſia, hypochondriaſis, and hepatic and viſceral obſtructions. The hurtful effects of ardent ſpirits, however, are obviated in a conſiderable degree by diluting them with water, and adding lemon-juice and ſugar to the mixture, ſo as to form what is generally known by the name of punch. Although all the varieties of ardent ſpirits may be regarded as diluted alcohol, yet each has a peculiar operation: thus,

brandy is simply cordial and stomachic; rum, heating and sudorific; gin and whisky, diuretic; and arrack, styptic, heating and narcotic, and ill adapted to European constitutions.

Vinous spirits, therefore, in small quantity, and properly diluted, may be applied to useful purposes in the relieving of some disorders; whilst in larger ones, or imprudently continued, they act as a poison of a particular kind. The moderate use of them is most serviceable to those who are exposed to heat and moisture, to corrupted air, or to other causes of colliquative and putrid diseases; and they are the most pernicious in opposite circumstances, and to those who are afflicted with hysterical and hypochondriacal complaints: for whatever temporary relief these spirituous cordials may afford in the lownesses to which hysterical and hypochondriacal persons are subject, there are none, as Dr. Pemberton observes, who feel so soon the ill effects arising from the habitual use of them. Lewis's Mat. Med.

The power of brandy, or any thing of this kind, in killing worms, is evident from this, that the children of the people in the northern islands of Scotland, who are accustomed from their infancy to drink that coarse sort of brandy which they call aqua vitæ, never are troubled with worms. It is a dangerous practice to use brandy in this general manner, but on some occasions it may be very serviceable. Philos. Trans. N° 233.

Spirits, *Laws relating to Foreign and British*. By a variety of statutes, which it would be too tedious here to enumerate, duties both permanent and temporary, of the customs and the excise, have been imposed on brandy, rum, arquebusade, geneva, arrack, and spirits, the amount of which is very considerable in proportion to the original price. By 43 Geo. III. c. 69. (sched. A), and 43 Geo. III. c. 81. several duties are imposed upon spirits imported; but by 49 Geo. III. c. 98. several duties of customs are imposed: the said duties are payable by the importer, before landing. If any person shall land any French brandy, before the duty be paid or secured, or without licence from the proper officer, and conceal the same when landed, he and his aider shall not only forfeit the same, but also double value; and if any officer of the customs or excise shall connive at it, he shall forfeit 500*l.*, and be incapable of holding any office in the revenue. (1 Ann. stat. 2. c. 14.) The officers of excise may go on board any ship and search, as officers of the customs may do, for any exciseable liquors, and seize such as shall be forfeited, and such as shall be unshipped before entry and payment of the duties, together with the casks and other package. (11 Geo. I. c. 30.) Any officer of the excise may search for concealed foreign spirits, and seize, &c.; and the penalty of obstruction is a forfeiture of 100*l.* By a general clause in 8 Geo. I. c. 18. all brandy, arrack, rum, spirits, and strong waters, and all foreign exciseable liquors, forfeited, together with the casks and package, may be seized by any officer of the customs or excise, or persons deputed from the lord treasurer, or under-treasurer, or by special commission under the great or privy seal, and no other person; and the penalty of obstruction is 40*l.* If any foreign brandy, arrack, rum, or strong waters, or spirits of any kind, shall be imported in any vessel of 100 tons burden, or under, (except for the use of seamen, not exceeding two gallons each,) such vessel, with its tackle, and also the spirits, shall be forfeited (5 Geo. III. c. 43.): except rum or other spirits of the growth and manufacture of the British sugar plantations, which may be imported in any vessel of not less burden than 70 tons. (6 Geo. III. c. 46.) If any vessel of 50 tons, or under, partly or fully laden with brandy, be at anchor or within two leagues of the shore, and not proceeding on her voyage, if wind and weather permit, such vessel may be compelled by the commander of any man of war, or armed sloop appointed to guard the coast, or the commander of any vessel in the service of the customs, to come into port; and the case is the same with ships hovering near the coasts. (6 Geo. I. c. 21.) If any vessel come from foreign parts, and have on board any foreign brandy or spirits, in casks under six gallons, (except for the use of seamen, not exceeding two gallons each,) shall be found at anchor, &c. as in the former case, all such spirits, with the casks and package, or value, shall be forfeited, and the same may be seized, or value sued for by the officers; and if the vessel do not exceed 50 tons in burden, the said vessel, with her tackle and furniture, shall be forfeited: and if any person, having charge of the vessel, shall suffer any brandy to be put into lighters or boats, in order to be landed, he shall, besides other penalties, suffer six months' imprisonment. No brandy shall be imported in any vessel not containing 60 gallons at the least, on pain of forfeiting the same, or value. (4 W. c. 5.) And no geneva or rum shall be imported in any vessel or cask, not containing 60 gallons at least, (except for the use of seamen, not exceeding two gallons each,) on pain of forfeiture. (5 Geo. III. c. 43.) If any officer shall find any increase of rum or spirits, (except such as have been imported and lodged in a warehouse, according to law,) above the quantity found on the last survey, or any decrease, (beyond the quantity legally delivered or allowed for leakage,) the proprietor or importer shall forfeit 500*l.*; and opening the warehouse, except in the presence of the warehouse-keeper or excise officer, incurs a forfeiture of 500*l.* If any rum or spirits remain in the warehouse above twelve calendar months (6 Geo. III. c. 47.), without paying the duty, the commissioners of excise may sell them by auction, and pay the duty and charges, transferring the overplus to the proprietor or importer. A permit shall be obtained for removal of the quantity sold; nor shall any liquor, exceeding one gallon, be carried away without such permit, on pain of forfeiting the same, with the casks and vessels. If the liquor be not removed, and the permit not returned, the person that took it out shall forfeit treble value. No person shall receive a permit, without direction in writing of the person (or his servant) from whose stock the goods are to be removed, on pain of 50*l.*; and in default of payment, three months' imprisonment. No foreign spirits, although under one gallon, shall be received into the custody of any retailer, without a permit, signifying that the duties were paid, or that they had been condemned, on pain of forfeiting the same. (8 Geo. I. c. 18.) No seller or dealer shall be allowed to take out more than one permit in one day; provided that several permits may be taken out, and casks containing foreign spirituous liquors sent to the same persons the same day, so that each cask may be sent under different permits, and by different conveyances; and provided dealers shall not be prevented from sending with one permit by one and the same conveyance any number of casks, containing 60 gallons each, or upwards, of the same kind. Foreign spirits, not being casks of 60 gallons, or upwards, shall not be removed, unless at the following times; that is, from September 29th to March 25th, yearly, between the hours of seven in the morning and five in the evening; and from March 25th to September 29th, between the hours of five and seven, (except the same is carrying by a known common stage-coach, waggon, or other stage carriage, usually travelling out of these hours,) on pain of forfeiture, with or without a permit. (23 Geo. III. c. 70.) No foreign spirits more than 60 gallons shall be brought to London by

one permit, or one conveyance, at the ſame time, from any part of England by land or water, (except by Graveſend, in the ordinary courſe of commerce,) on pain of being ſeized and forfeited. (26 Geo. III. c. 73.) If any perſon ſhall counterfeit a permit, or give or receive any falſe permit, or alter any granted by the proper officer, he ſhall forfeit 500*l.* 23 Geo. III. c. 70.

For the conditions, regulations, and reſtrictions, under which rum imported from the Weſt Indies may be ſecured in warehouſes, without payment of duty, ſee 43 Geo. III. c. 132. 45 Geo. III. c. 87. 46 Geo. III. c. 137. and 48 Geo. III. c. 126; and for thoſe under which brandy, geneva, and other ſpirits, may be ſecured in warehouſes, without payment of duty, ſee 43 Geo. III. c. 132. 45 Geo. III. c. 87. 46 Geo. III. c. 137. and 48 Geo. III. c. 126. For other laws and regulations, ſee CUSTOMS, DISTILLER, EXCISE, SMUGGLING, and WINE.

SPIRIT *of Ammonia*, in the *Materia Medica*, is prepared, according to the directions of the Lond. Ph., by mixing two pints of rectified ſpirit with a pint of ſolution of ammonia. The "ammoniated alcohol," formerly *ſpirit of ammonia*, of the Ed. Ph., conſiſts of 32 oz. of alcohol (835), 12 oz. of lime recently burnt, and 8 oz. of muriate of ammonia; and is prepared in the ſame manner as water of ammonia. (See AMMONIA.) The *ſpirit of ammonia* of the Dub. Ph. is prepared by mixing three pints of proof-ſpirit, 4 oz. of muriate of ammonia, and 6 oz. of potaſhes; and diſtilling, with a moderate heat, two pints. This ſpirit, properly prepared, has the pungent odour and acrid taſte of ammonia, with which it coincides in its medicinal properties. (See AMMONIACAL *Preparations*.) It is chiefly uſed for pharmaceutical purpoſes. The official preparations are "ſpiritus ammoniæ compoſitus," "ſpiritus ammoniæ fœtidus," "tinctura caſtorei compoſita," "tinctura guaiaci compoſita," and "tinctura opii compoſita."

SPIRIT *of Ammonia, Aromatic*, is prepared, according to the Lond. Ph., by mixing two pints of ſpirit of ammonia with oil of lemon and oil of cloves, of each two fluid-drachms. The "aromatic ammoniated alcohol," formerly *aromatic ſpirit of ammonia*, of the Edinb. Ph., is compoſed of 8 oz. of ammoniated alcohol, 1½ drachm of volatile oil of roſemary, and a drachm of volatile oil of lemons, which are mixed ſo as to diſſolve the oils. The *aromatic ſpirit of ammonia* of the Dub. Ph. is formed by digeſting two pints of ſpirit of ammonia, two drachms of eſſential oil of lemons, and half an ounce of bruiſed nutmegs, in a covered veſſel for three days, frequently ſhaking the veſſel; and then diſtilling a pound and a half. This ſpirit is an uſeful ſtimulant in languors, and flatulent colic; and the oils render it more grateful to the ſtomach than the ſimple ſpirit of ammonia. The doſe is from f℥ſs to f℥j, in any convenient vehicle. The official preparations are "tinctura guaiaci ammoniata," and "tinctura valerianæ ammoniata."

SPIRIT *of Ammonia, Fœtid*, is prepared, according to the Lond. and Dub. Ph., by macerating two pints of ſpirit of ammonia, and 2 oz. of aſſafœtida (1½ oz. Dub.), for 12 hours (for three days, in a covered veſſel, with frequent agitation, Dub.); and then by a gentle fire diſtilling a pint and a half into a cold receiver. The "fœtid ammoniated alcohol," formerly *fœtid ſpirit of ammonia*, of the Edinb. Ph., is prepared by digeſting 8 oz. of ammoniated alcohol, and ½ oz. of aſſafœtida, in a cloſe veſſel for 12 hours, and then diſtilling 8 oz. by the heat of boiling water. The medicinal properties of this ſpirit, and the doſe, are the ſame with thoſe of the preceding. It acquires colour from age.

SPIRIT *of Ammonia, Succinated*, of the Lond. Ph., is prepared by macerating three drachms of maſtich in nine fluid-drachms of alcohol, ſo that it may be diſſolved, and pouring off the clear tincture; then adding fourteen minims of oil of lavender, four minims of oil of amber, and ten fluid-ounces of ſolution of ammonia, and mixing them by agitation. This ſpirit is employed as a ſtimulant and antiſpaſmodic, in the ſame caſes as the oil of amber, and has been uſed with ſucceſs in India againſt the bite of the rattle-ſnake. The doſe is from ♏x to f℥ſs, in any convenient vehicle. See AMBER.

SPIRIT *of Aniſe-ſeed* of the Lond. Ph. is formed by macerating for 24 hours half a pound of aniſe-ſeeds bruiſed, a gallon of proof-ſpirit, and a ſufficient quantity of water to prevent empyreuma, and diſtilling by a gentle fire. The *compound ſpirit of aniſe-ſeed* of the Dub. Ph. is obtained by diſtilling one gallon from aniſe-ſeeds and angelica ſeeds bruiſed, of each half a pound, a gallon of proof-ſpirit, and water ſufficient to prevent empyreuma. In flatulent colic, and ſimilar affections, theſe are pleaſant carminatives. The doſe is from f℥ſs to f℥iv, in water.

SPIRIT *of Horſe-radiſh, Compound*, "ſpiritus armoraciæ compoſitus," of the Lond. Ph., is prepared by macerating freſh horſe-radiſh ſliced and orange-peel dried, of each a pound, half an ounce of nutmegs bruiſed, a gallon of proof-ſpirit, and water ſufficient to prevent empyreuma, for 24 hours, and diſtilling a gallon by a gentle fire. (See COCHLEARIA.) The "compoſitus ſpiritus raphani," of the Dub. Ph., is formed by diſtilling two gallons from horſe-radiſh dried and peel of Seville oranges, of each two pounds, four pounds of freſh garden ſcurvy-graſs, one ounce of nutmegs bruiſed, two gallons of proof-ſpirit, and water ſufficient to prevent empyreuma. Theſe ſpirits, which were formerly uſed as antiſcorbutics, are now held in little eſtimation in that intention. They are chiefly uſed in dropſies, attended with much debility. The doſe is from f℥j to f℥iv, combined with infuſion of fox-glove or juniper-berries.

SPIRIT *of Camphor* of the Lond. Ph. is prepared by mixing four ounces of camphor with two pints of rectified ſpirit, that the camphor may be diſſolved. The "tincture of camphor," commonly called the "camphorated vinous ſpirit," is obtained by mixing one ounce of camphor with one pound of alcohol (ſp. gr. 835), ſo that the camphor may be diſſolved. It may be alſo made with double or triple the quantity of camphor. This ſpirit is too ſtrong to be given internally; and if water be mixed with it, the camphor is ſeparated. It is an uſeful ſtimulant and diſcutient application to chilblains, and in chronic rheumatiſm, paralytic numbneſs, and gangrene. See CAMPHOR.

SPIRIT *of Carraway* of the Lond. and Dub. Ph. is obtained by macerating a pound and a half (half a pound, Dub.) of carraway ſeeds bruiſed in a gallon of proof-ſpirit, and water ſufficient to prevent empyreuma, for 24 hours, and diſtilling a gallon by a gentle fire. The *ſpirit of carraway* of the Edinb. Ph. is prepared by macerating half a pound of carraway ſeeds bruiſed in nine pounds of proof-ſpirit, for two days in a cloſe veſſel, adding water enough to prevent empyreuma, and diſtilling nine pounds. This ſpirit is an uſeful carminative, and an adjunct to griping purgatives. See CARUM.

SPIRIT *of Cinnamon* of the Lond. and Dub. Ph. is prepared by macerating one pound of cinnamon bark bruiſed in a gallon of proof-ſpirit, and water ſufficient to prevent empyreuma, for 24 hours, and diſtilling a gallon by a gentle fire. The *ſpirit of cinnamon*, "ſpiritus corticis lauri cinnamomi," of the Edinb. Ph., is prepared with a pound of cinnamon bark, in the ſame manner as the ſpirit of carraway.

This ſpirit is an agreeable cordial in diſeaſes attended with much languor and debility. The doſe is from fʒj to fʒiv, in any ſuitable vehicle. The officinal preparation is "infuſum digitalis." See Cinnamon.

Spirit, *Coal.* See Coal.

Spirit *of Sulphuric Ether* of the Lond. Ph. is obtained by mixing half a pint of ſulphuric ether (ſee Ether) with a pint of rectified ſpirit. The "ſulphuric ether with alcohol," of the Edinb. Ph., is prepared by mixing one part of ſulphuric ether with two parts of alcohol. The ſpecific gravity of this mixture is .816. It may be uſed for the ſame purpoſes as the ether, but it is much leſs active. The doſe is from fʒj to fʒiij. An uſeful gargle for ſlight inflammation of the fauces is prepared by adding fʒj of this ſpirit to f℥vi of boiling water, ſweetened with f℥iv of ſyrup of marſh-mallows. The ſulphuric ether, of which this is an officinal preparation, is ſtimulant, narcotic, and antiſpaſmodic. In its operation it reſembles alcohol, but is more diffuſible, and its effects are leſs permanent. It is beneficially employed as a cordial in typhoid and low fevers, particularly when nauſea, ſubſultus tendinum, and other ſpaſmodic ſymptoms are preſent. As an antiſpaſmodic, it relieves the paroxyſm of ſpaſmodic aſthma, whether it be taken into the ſtomach, or its vapour only be inhaled into the lungs; in which latter form it is alſo uſeful in ſimple dyſpnœa and in catarrh. It is employed with advantage in hyſteria, tetanus, cramp of the ſtomach, hiccough, and in cholera morbus to check the vomiting; and alſo allays the violence of ſea-ſickneſs. The uſual doſe of ſulphuric ether is from fʒſs to fʒij; but it has been given in much larger doſes with the moſt beneficial effects; and in all caſes, the doſe muſt be repeated at ſhort intervals, to produce the full effect of the remedy. As an external application, ether acts either as a ſtimulant or a refrigerant, according to the mode in which it is applied. The firſt takes place when it is prevented from evaporating, by being confined over the ſpot to which it is applied; in which caſe it often proves uſeful in relieving head-ache, and other muſcular pains: and from its refrigerant effect produced by its rapid evaporation, it is applied to burns, and to aſſiſt in the reduction of ſtrangulated hernia. It has produced, ſays Thomſon (Lond. Diſp.), almoſt immediate relief in ear-ache, when dropped into the external meatus.

Spirit *of Ether, Aromatic,* of the Lond. Ph., is obtained by macerating three drachms of cinnamon bark bruiſed, a drachm and a half of cardamom ſeeds powdered, long pepper powdered and ginger-root ſliced, of each a drachm, in a pint of ſpirit of ſulphuric ether, for 14 days, in a ſtopped glaſs-bottle, and ſtraining. The "aromatic ſulphuric ether with alcohol," of the Edinb. Ph., is made with the ſame aromatics, and in the ſame manner as the compound tincture of cinnamon, except that ſulphuric ether with alcohol is employed inſtead of proof-ſpirit. The medicinal properties of theſe preparations are the ſame with thoſe of the former; the aromatics rendering them in a ſlight degree more grateful.

Spirit, *Ethereal, of Frobenius, Spiritus Etherius Frobenii,* a name given by Frobenius, and others, to a liquor famous for its extreme volatility, and many other qualities; for which ſee *Sulphuric* Ether.

The uſe of this liquor in medicine is now well known: as a very thin and volatile inflammable matter, it acts powerfully on the nervous ſyſtem. Frederic Hoffman was one of the firſt who employed it as a ſedative and antiſpaſmodic. See Liquor *Mineralis Anodynus,* and Spirit *of Ether, infra.*

It is now often preſcribed ſingly, in the doſe of ſeven or eight drops upon a bit of ſugar, which is to be eat, or to be diſſolved in ſome proper liquor, and drank. It is given in flatulent colics, obſtinate hiccoughs, convulſive hyſterical affections, and other diſorders of this kind. This ether is ſaid to take ſpots of greaſe from ſilk, without affecting their colours.

We have ſeveral curious obſervations on this ether of Frobenius by Mr. Groſſe, who has deſcribed three different methods of making it in the Memoirs of the Academy of Sciences, for the year 1734.

Spirit *of Ether, Compound,* of the Lond. Ph., is prepared by mixing a pint of ſpirit of ſulphuric ether with two fluid-drachms of ethereal oil. (See *Sulphuric* Ether.) This is intended as a ſubſtitute for the anodyne liquor of Hoffman (ſee the preceding article); for, beſides being ſtimulant and antiſpaſmodic, it is ſuppoſed to poſſeſs anodyne properties. It is an uſeful addition to tincture of opium, when given for the purpoſe of procuring ſleep; and it often prevents the opium from exciting the nauſea which it is apt to produce in ſome habits. The doſe is from fʒſs to fʒij, in any appropriate vehicle.

Spirit *of Juniper, Compound,* of the Lond., Dub., and Edinb. Ph., is prepared by macerating one pound of juniper-berries bruiſed, carraway ſeeds and fennel ſeeds bruiſed, of each an ounce and a half, in a gallon (nine pounds, Edinb.) of proof-ſpirit, for 24 hours (two days, Edinb. and Dub.); and then diſtilling a gallon (nine pounds, Edinb.) by a gentle heat. This ſpirit is a grateful and uſeful addition to infuſions of fox-glove, and other diuretics, in dropſy. See Juniperus.

Spirit *of Lavender.* See Lavandula.

Spirit *of Libanus, Smoking.* See Liquor.

Spirit *of Malt.* See Malt-*Diſtillery.*

Sipirit *of Mindererus.* See Acetite *of Ammonia,* Liquor, and Vinegar.

Spirit, *Moloſſes.* See Moloſſes-*Spirit.*

Spirit *of Nitre.* See Nitric *Acid,* and *Nitrat* Potassæ.

Spirit *of Nitric Ether* of the Lond. Ph. is obtained by taking two pints of rectified ſpirit, and three ounces (by weight) of nitric acid. Add the acid gradually to the ſpirit, and mix them, taking care that the temperature, during the mixture, does not exceed 120°; then diſtil, by a gentle heat, 26 fluid-ounces. *Spirit of nitrous ether* of the Edinb. Ph. is prepared by pouring three pounds of alcohol into a large phial placed in a veſſel full of cold water, and adding one pound of nitrous acid gradually, with frequent agitation. Slightly cork the phial, and place it in a cool place for ſeven days; then diſtil the liquor, by the heat of boiling water, into a receiver kept cool with ſnow or water, as long as any ſpirit comes over. The *nitrous ethereal ſpirit* of the Dub. Ph. is prepared in the following manner: Add to the matter which remains after the diſtillation of nitrous ether, the rectified ſpirit of wine, employed in that operation for condenſing the elaſtic vapour, and diſtil to dryneſs, with the greater heat of a water-bath. Mix the diſtilled liquor with the alkaline liquor which remains after the ſeparation of the nitrous ether, and alſo add as much dry ſubcarbonate of kali as ſhall be ſufficient to ſaturate the predominant acid; which is to be determined by the teſt of litmus. Laſtly, diſtil by the medium heat of a water-bath, as long as any fluid comes over. The ſpecific gravity of this liquor is to that of diſtilled water, as 850 to 1000. The ſpirit of nitric ether, as procured by the London or Edinburgh proceſs, has an extremely fragrant odour, and a pungent acidulous taſte. It is very volatile and inflammable, ſoluble in water and alcohol, and ſtrikes a deep

olive with ſolution of green ſulphate of iron. See *Nitrous* ETHER.

Spirit of nitric ether is refrigerant, diuretic, and antiſpaſmodic. It has been long known and uſed, under the title of "ſweet ſpirit of nitre," as a grateful refrigerant, and for quenching thirſt in febrile affections; for which purpoſe the doſe is from ♏xx to ♏xl, given in a cupful of water, or any other appropriate vehicle. In larger doſes it acts as a gentle ſtimulant to the ſtomach, relieving nauſea and flatulence; and alſo determines to the kidnies, increaſing the flow of urine; on which account it is advantageouſly preſcribed as an auxiliary to other diuretics in dropſical complaints. The dulcified ſpirit of nitre is added by drops to potions and juleps, till it has given them an agreeable acidity.

It is alſo much uſed by our diſtillers to give a vinoſity to thoſe ſpirits, whoſe natural flavour of that kind they have deſtroyed by the improper uſe of alkaline ſalts in the rectifications. Nothing can be more proper for this purpoſe than this ſpirit, as it really gives the brandy-flavour, and is not at all prejudicial to health, but very well falls in with the nature of the ſpirit, and promotes its medicinal properties as a diuretic, deobſtruent, and lithontriptic.

It has been ſuggeſted, that the method of making it for this purpoſe is improveable, by uſing in the preparation a ſpirit of wine impregnated with ſome fine flavoured ingredient, which has not much oil, for acids do not readily mix where there is much oil.

In the preparation of this dulcified ſpirit of nitre, the longer it ſtands in digeſtion with the ſpirit of wine, the milder it grows; and by the ſame means alſo, the violently corroſive oil of vitriol may be ſo blunted, as to be rendered ſcarcely perceptible to the taſte. In fine, it has been ſaid that a ſpiritus nitri dulcis may be made, by a ſlow digeſtion, greatly ſuperior to that commonly uſed, and of ſo fixed a nature, that it will not be ſubject to have its flavour fly off from the ſpirit with which it is mixed, any ſooner than the native vinoſity of brandy will of itſelf fly off from that ſpirit, as it always will in time. A proper care in the preparation of this acid might free the diſtillers from that troubleſome neceſſity they are under of adding their ſpirit of nitre, juſt before they ſend their goods away, for fear the flavour ſhould be loſt before the ſpirit is wholly uſed, and ſo the ſophiſtication be found out. There is no fixing any certain proportion in which the acid is to be mixed with the ſpirit, but in general it is beſt not to over-do it; for though it will give an agreeable vinoſity to any tolerable clean ſpirit, the perſon will be much deceived who attempts to drow nhe bad flavour of a foul one by it. Shaw's Eſſay on Diſtillery.

Mr. Woulfe deſcribes an apparatus by which *nitrous ether* (in the article under ETHER) may be expeditiouſly obtained by diſtillation, with the heat only occaſioned by mixing together the nitrous acid and the ſpirit of wine. This diſtillation is performed in a matraſs with a high neck, to which is fitted a head with a ſpout, communicating with the receiver by means of a long tube. The vapours that are not condenſed in this receiver, or in a bottle joined to a ſpout in its bottom, are conveyed from the receiver through a bent tube into ſpirit of wine contained in a bottle. If any vapours paſs uncondenſed through this ſpirit of wine, they are conveyed through another bent tube into more ſpirit of wine contained in another bottle. The liquor collected in the bottle annexed to the receiver, being ſlowly rectified with ſlaked lime, furniſhes very fine ether. The ſpirit of wine in which the vapours were condenſed, contains ſo much ether, that this fluid may be ſeparated from the ſpirit by adding water. This ſpirit of wine is by the operation changed into good dulcified ſpirit of nitre. Phil. Tranſ. vol. lvii. art. 59.

SPIRIT *of Sal Ammoniac.* See AMMONIACAL *Preparations.*

SPIRIT *of Salt.* See MURIATIC *Acid.*

SPIRIT *of Sulphur*, or *of Vitriol.* See SULPHURIC *Acid.*

SPIRIT *of Turpentine.* See TURPENTINE.

SPIRIT *of Venus.* See ACETIC *Acid.*

SPIRIT *of Vinegar.* See ACETOUS *Acid*, and VINEGAR.

SPIRIT *of Vitriol.* See SULPHURIC *Acid*, and VITRIOL.

SPIRIT *of Wine.* See ALCOHOL and WINE.

Spotting

SPOTTING, Finger, known alſo by the name of *Brocading*, in the *Manufacture of fanciful ornamented Cloths*, is a very beautiful, though rather expenſive, mode of interweaving flowers, either of the ſame or different colours, with various kinds of grounds. Of its primary origin we are totally unacquainted, as we find it practiſed alike, and with little variation of apparent effect, in the ſilks of Europe and the muſlins of India. It is probable that the whole range of fanciful cloths, with which we are acquainted, are originally Aſiatic; and that the knowledge of them has gradually reached Europe, at various times, and through various channels. In ſpots wrought with the ſhuttle, the flowers being at intervals, and the woof paſſed acroſs the whole fabric, what paſſes between the flowers, and is not interwoven with the fabric, muſt be cut away, when the cloth is taken from the loom, and before it undergoes the ſucceeding proceſſes of bleaching and dreſſing. Some ſpecimens of brocaded muſlins have been occaſionally brought from India, which are entirely effected by a continued and patient exerciſe of manual labour truly aſtoniſhing. The low price of labour paid to the natives of that country may produce theſe figured muſlins, at prices acceſſible to the opulent natives, and to the more wealthy claſſes of the European ſettlers. In this country, even at the moſt reduced prices, capable of affording to the operative the moſt penurious and ſcanty ſubſiſtence, they could not be afforded under four or five guineas *per* yard; a ſum immenſely beyond what could be expected for a commodity ſo flimſy and periſhable as a muſlin dreſs.

In finger-flowers, or brocaded muſlins, the draught through the heddles is generally ſucceſſive from the back to the front, as in moſt kinds of fanciful weaving. The treddles are moved by the feet, as in the common proceſſes, for forming the plain ground or fabric of the work. For the flowers or raiſed part, thoſe leaves which require to be raiſed are moſt commonly pulled by cords above the weaver's head, as in the diaper and patent draw-loom; and, like them, ſecured by a knot upon the cord, being fixed in a notch in the board. The weaver then proceeds to paſs the ſubſtance, which is to form the flowers, through the warp; each end being ſeparated from, and independent of, all the others. In this he is generally aſſiſted by a boy, who ſits at the loom along with him, and who manages one ſide of the web, while the weaver is employed on the other. From this tedious and laborious operation being done entirely by the fore-finger, the appellation *finger-flower* is derived. Our limits will not allow of a very lengthened detail, nor would it be of any eſſential ſervice; for, from the cauſes already aſſigned, there is no probability of its ever becoming an article of extenſive manufacture in this country.

Staffordshire

STAFFORDSHIRE is an inland county, fituated nearly in the centre of England, between 52 and 54 degrees N. latitude, and between one and three degrees W. longitude from London. It is in fhape an irregular parallelogram; and is bounded on the N. by Chefhire and Derbyfhire, on the E. by Leicefterfhire, on the S. by the counties of Warwick and Worcefter, and on the W. by Shropfhire. Its greateft length from N.N.E. to S.S.W. is about 60 miles, and its greateft breadth from E. to W. 38 miles. The fuperficial contents are about 780,800 acres, of which 100,000 are pafture, 500,000 arable, and the remaining 180,800, woods, waters, waftes, &c.

Ancient State: Hiftorical Events.—This county appertained to the Cornavii of the Britons, to the divifion of Flavia Cæfarienfis of the Romans, and was a part of the kingdom of Mercia during the Saxon heptarchy. Bede calls the inhabitants Angli-Mediterranei, the midland Englifh. The two Roman military ways, Watling-ftreet and Icknield-ftreet, pafs through this county. The former enters it out of Warwickfhire, near Tamworth, and running weftward paffes into Shropfhire. Icknield-ftreet alfo enters from Warwickfhire at the village of Hanfworth, near Birmingham, croffes Watling-ftreet, and enters Derbyfhire at Monk's bridge. The Roman ftations in this county that are known, are Pennocrucium, near Stretton; and Etocetum, at Wall near Lichfield. But Salmon gives to Staffordfhire four Roman ftations, which, he fays, are Mediolanum, at Knightley; Uriconium, at Wrottefley; Uxacona, at Wall-Lichfield; and Etocetum, at Barbeacon. The firft of thefe ftations Camden pofitively fixes in Montgomeryfhire; and bifhop Horfley places it on a flip of land inclofed by the Tern and another river. Salmon affigns Pennocrucium to Oldbury, in Warwickfhire, and refers to Antoninus's fecond Iter for his authority; but Plot, Gale, Horfley, and Stukeley, coincide in opinion that Penkridge is the fcite of that ftation. The ancient inhabitants of Staffordfhire, in the opinion of Dr. Plot, were the Iceni; but in this he ftands unfupported: Shaw fays that tribe was undoubtedly of Derbyfhire. Camden and Gough will not allow that they extended beyond Huntingdonfhire, weftward; while Salmon confines them to Norfolk and Suffolk. Shaw fuppofes that the Ordovices were the original inhabitants of this diftrict, and it is generally agreed that they poffeffed it many centuries before the Chriftian era. Thefe were an intrepid warlike people, whofe territories comprifed a great portion of Wales and feveral counties of England. But they were difturbed in their poffeffions by the Cornabii, who, breaking through the limits of their original fettlements on the banks of the Dee, conquered a large tract of country to the weft and north-weft, and eftablifhed a monarchy, of which Condate was the capital. The Brigantes, in their turn fubdued a portion of the territories of this tribe a fhort time previous to the arrival of the Romans. On this event the metropolis was transferred from Condate to Uriconium, now Wroxeter, where it continued a confiderable time, till the Romans extended their conqueft into the interior of the country. During the fanguinary contefts which enfued, little is recorded refpecting this diftrict and its inhabitants, but that they heroically refifted the invaders, and though at length compelled to fubmit, their courage and ardour for freedom excited the admiration of their conquerors. The Cornabii, after the fubjection of their country, appear to have been the friends and allies of the Romans. It is remarkable that after the decline of the Roman power, the appellation Cornabii never occurs in the annals of Englifh hiftory. When the Britons experienced a fecond fubjugation by the Saxons, and the heptarchy was eftablifhed, Staffordfhire formed a part of the kingdom of Mercia, which extended over all the midland counties, and was founded by Crida in the year 585. During the repeated invafions of the Danes, this county fuftained a confiderable part of the calamities confequent on their cruelty and rapacity. Several fanguinary battles took place within the kingdom of Mercia; in Staffordfhire particularly, two victories were obtained over the Danes in the reign of Edward the Elder. On the partition of England between Edmund Ironfide and Canute, this county, as part of Mercia, was awarded to the latter. After the Norman conqueft, William divided the eftates of the Mercian earls among four of his principal followers, Hugh de Montgomery, earl of Arundel; Robert de Stafford, Henry de Ferrars, and William Fitz-Anfculph; the laft of whom held twenty-five manors in this county. The other principal landholders befides the king, were the bifhop of Chefter, the abbots of Weftminfter and Burton, the church of Rheims, and the canons of Stafford and Wolverhampton. During the contention between the royal houfes of York and Lancafter, a decifive battle was fought at Bloreheath, in this county, between the Yorkifts under the earl of Salifbury, and the Lancaftrians under lord Audley, when the latter, with double the force and fuperior pofition, was completely defeated, himfelf flain, and 2400 Chefhire gentlemen, whofe attachment to king Henry led them into the van, alfo fell in the action.

In the civil war of the feventeenth century, Staffordfhire was confiderably engaged: Stafford furrendered to the parliament's forces, and Lichfield was feveral times taken and retaken by the contending parties. In this county Charles II. lay concealed after the fatal battle of Worcefter, till he had an opportunity of efcaping. The circumftances attending his concealment, the difficulties he fuftained, and the unfhaken loyalty of his friends, are amply detailed by Mr. Shaw in his General Hiftory of Staffordfhire.

Ecclesiastical History.—Staffordshire did not receive the light of the gospel till the reign of Penda, king of Mercia, whose son, Peadda, was converted to Christianity by the venerable Bede. This was soon declared the established religion of Mercia, and the cathedral of Lichfield was founded, where the episcopal see of Mercia was fixed in 669; but it was soon afterwards divided into five several dioceses, and Lichfield, Worcester, Hereford, Leicester, and Sidnacester, chosen for the respective sees. In the year 786, at the request of king Offa, pope Adrian advanced Lichfield to the dignity of an archbishopric; but this distinction was continued only till the death of Offa, when pope Leo reduced it to its former rank. About the year 1067 the episcopal seat was removed to Chester, and thence soon afterwards to Coventry, where it continued till the end of the thirteenth century, when Walter de Langton was appointed bishop of Lichfield and Coventry. From this period nothing remarkable occurred in Staffordshire, connected with church history, previous to the reformation, when Lichfield cathedral was despoiled of the rich shrine of St. Chad, and the see of Coventry separated from it. The two bishoprics remained distinct till the restoration, when they were again united in the person of Dr. John Hacket. Since that time the diocese has undergone no particular alteration. Staffordshire, which is comprised in this see, contains 181 parishes.

Civil Division.—Staffordshire is divided into five hundreds; Totmanslow, Pyrehill, Cuddlestone, Offlow, and Seisdon: and contains one city, Lichfield, and twenty-three other market-towns, *viz.* Stafford, Wolverhampton, Walsall, Burton-on-Trent, Uttoxeter, Newcastle, Leek, Stone, Cheadle, Eccleshall, Rudgeley, Tamworth, Tutbury, Abbot's-Bromley, Breewood, Penkridge, Cannock, Wednesbury, Burslem, Handley-Green, Lane-End, and Longnor. Ten members are returned to the imperial parliament from this county, *viz.* two for the shire, and two each for Lichfield, Stafford, Newcastle, and Tamworth. According to the population survey of the year 1811, this county contained 57,040 houses, occupied by 295,153 persons; of whom 34,011 families were chiefly employed in trade and manufactures, and 18,361 in agriculture.

General Aspect, Soil, and Climate.—The appearance of the county varies in different districts. The middle and south portions are generally level: among the few exceptions are the hills of Dudley and Sedgeley, the quartose and ragstone hills of Rowley, and those of Clent and Barbeacon. The grounds of Byshbury and Essington, and some situations near Tettenhall and Enville, as well as on Cannock-heath, are also considerably elevated. The latter portion of the county was in ancient times covered with oak, but most of these have been destroyed: indeed scarcely a tree now remains to enliven the prospect, through an extent of 2500 acres. The northern portion of the county is of an opposite character to that on the south. Here the surface is mostly bleak and hilly: only a few of the eminences, however, rise to any remarkable elevation. The summit of Bunster, near Ilam, was found by Mr. Pitt, in the course of his "Agricultural Survey," to be 1200 feet above the level of the Thames. The Weever hills, and some other points, he reports as ascending even 1500 feet. The general elevation of this district above the southern is estimated at from one to two hundred yards. That portion of it called the moorlands, is the commencement of that range of mountains which extend through the centre of England, till they enter Scotland, acquiring different appellations in their progress, and increasing in altitude as they approach the north. The *soil* is extremely varied. The arable soils may be divided generally into the argillaceous, or stiff and strong clayey; the arenaceous, or loose, light, and sandy; the calcareous, or lime earth; and a mixed or compound soil, or loam composed of the foregoing, with the addition of stones and other matters. The *climate* of this county inclines to wet: the annual rains are calculated at upwards of 36 inches, and thus exceed by nearly 16 inches the average computation of rain in London. A great quantity of snow falls in the moorlands, which doubtless is a principal cause of the piercing cold which prevails in that district.

Rivers.—Staffordshire abounds with rivers, but none of them are navigable, at least within the county. The principal are the Trent, the Dove, the Tame, and the Blythe. The Trent, which may be considered as the third river of England, waters, in its course to the sea, some of the most fertile and best cultivated districts of the kingdom. During its passage through Staffordshire, its banks are covered with luxuriant meadows. In the vicinity of Trentham, the seat of the noble family of Gower, the efforts of art have greatly added to the natural beauty of the river, by swelling it into an expansive lake. Passing the town of Stone, it flows through a valley diversified with a variety of elegant parks; of which that of Wolsey, bordering on the chase of Cannock, is one of the most remarkable for the romantic beauty of its scenery. Pursuing its course, the Trent becomes the boundary between the counties of Stafford and Derby, till its junction with the river Dove; then, crossing Derbyshire, it runs through the counties of Nottingham and Lincoln, and at length pours its waters into the Humber. The Dove takes its rise among the hills in the moorlands, near the points where the counties of Stafford, Derby, and Chester meet. From the declivity of its channel, its waters flow with uncommon rapidity: in some places it dashes precipitately over rugged rocks; in others it is distinguished by gentle cascades. It falls into the Trent near Burton, on the confines of Derbyshire. The Tame, another river of considerable size, springs from several sources in the vicinity of Walsall and Coleshill, enters Warwickshire near Birmingham, returns into Staffordshire at Tamworth, and finally joins the Trent. The Blythe rises in the neighbourhood of Watley moor, in the northern district. Its course is nearly parallel to the Trent, into which it falls near King's-Bromley.

Canals.—Although an inland situation, without navigable rivers, appears to labour under peculiar disadvantage for the purposes of trade; yet in Staffordshire the deficiency is amply compensated by the number and extent of the canals, with which this county is so largely supplied. The principal are the Grand Trunk Canal, the Coventry and Oxford, and the Birmingham Canal. These, with their numerous branches and ramifications, have already been particularly described. See CANAL.

Lakes and Springs.—This county affords but few lakes, and those of no great consequence. Those most worthy notice are that of Aquilate, which extends 1848 yards in length, and 672 in breadth; and Ladford Pool, which occupies the space of about 60 acres. Salt springs are found in various places. The most considerable are those in the parish of Weston, whence salt is produced, equal in quality and colour to that of any part of the kingdom.

Minerals.—The number and value of the mineral productions of Staffordshire claim particular notice. Coal is abundant: upwards of 50,000 acres have been ascertained to contain an inexhaustible supply, near enough to the surface to be easily raised. From the earliest times to the present, the consumption does not appear to have exceeded a tenth part of the whole. In the southern division of the county, the coal district extends in length from the interior

of Cannock-heath to the vicinity of Stourbridge, and in breadth from Wolverhampton to Walfall. To the north, likewife, it abounds in the neighbourhood of Newcaftle and the Potteries, Lane-End, Hollybrufh, Cheadle, and Dillhorne. At Handley-Green a very peculiar fpecies is dug, called the Peacock coal, from the prifmatic colours it difplays. Limeftone is ftill more abundant than coal. At Sedgeley and Dudley-caftle hills, Rufhall and Haywood, and on the north-eaft moorlands, the quantity is immenfe. The lime-works upon Caldon Low, and near the Weever hills, are particularly extenfive. This ftone is, in fome places, of a marble quality, and capable of taking a fine polifh. In other parts it is chiefly compofed of trelmintholopi, or petrified marine fubftances of the animal kind. Iron ore is plentiful throughout the coal diftrict. Near Wednefbury, Tipton, Bilfton, and Sedgeley, and to the weft of Newcaftle, it is peculiarly excellent and abundant. The ftrata are generally ranged beneath a ftratum of coal. Iron-works of great extent have been recently eftablifhed on the banks of the Birmingham Canal; and the trade is fo rapidly increafing, as to afford a profpect of its precluding the neceffity of any confiderable importation. Copper and lead ore alfo abound in this county. A copper-mine is worked at Mixon, near Leek; but a more important one at Ecton-hill, near Warflow, on the eftate of the duke of Devonfhire. This hill has likewife a confiderable vein of lead; and another of the fame mineral has been found near Stanton-moor. In this part of the county, but particularly at Whifton, Oakmoor, and Cheadle, fmelting and brafs-works are carried on to a confiderable extent. Quarries of good free-ftone for various purpofes are found in the different diftricts. A durable kind for building, eafily raifed in blocks of any dimenfion, is found at Tixal. Alabafter was formerly dug in great quantities, particularly on the banks of the Dove; but though it ftill exifts in plenty, very few of the quarries are now wrought. This county alfo yields various kinds of marble: that fpecies, to which the name of rance-marble is given, abounds on Yelperfley Tor, and the adjacent hills. Clays of every denomination are abundant. Amblecot produces a clay of a dark-blue colour, of which are made the beft glafs-houfe pots of any in England. Glafs-houfes have, in confequence, been erected in the neighbourhood; and great quantities of the clay are fent to different parts of the kingdom. Potters' clay of various forts is found here, particularly in the vicinity of Newcaftle, where the potteries are chiefly carried on. Yellow and red ochre, and other earths ufed for colouring and painting, are among the productions of this county. At Darlafton, near Wednefbury, is a blue clay, which is fold to glovers to dye afh-colour. A black chalk is found in the beds of grey marble in Langley Clofe; and under a rock near Hemley Hall is a reddifh earth, nearly equal to the red chalk of France.

The farms of Staffordfhire are of all extents, from fifty acres to five hundred; but the number of the fmaller has been lately much diminifhed. The rent of land varies from 15*s*. to 40*s*. *per* acre, making the average about 25*s*. The cultivated lands of this county are nearly all inclofed, not more than 1000 acres ftill remaining open. The fences in the fouthern part are chiefly raifed from quickfets, among which the white thorn is moft approved.

Timber, Plantations, and Woodlands.—This county, notwithftanding the great recent confumption, is abundantly ftocked with wood of every defcription. Lord Bagot's eftate, near Abbot's-Bromley, contains feveral acres of oaks, not to be furpaffed in quality by any in the kingdom: the timber in many of them is to the height of fixty or feventy feet. Chillingworth eftate ranks next to this for the value of its woods. Thofe at Beaudefert, the feat of the earl of Uxbridge, and thofe at Lhmley, the property of lord Dudley, are alfo very extenfive. Teddefley has very confiderable plantations. Manfley wood is a coppice of fine oak. Wrottefley, Fifherwick, Trentham park, Sandwell park, Enville, and Hilton, difplay abundance of well-grown trees of every defcription.

Wafte Lands.—The extent of uncultivated lands in this county is very great; being computed by Mr. Pitt to amount to an hundred thoufand acres. The chief wafte diftricts in the fouthern parts are Cannock-heath and Sutton-Coldfield, with Swindon, Wombourn, and Fradley commons. In the north are Morredge, Wetley-moor, Stanton-moor, Hollington-heath, Carefwell-common, and Needwood foreft; which laft, however, has been in part recently inclofed and cultivated.

Manufactures and Commerce.—Various branches of manufacture are carried on to a great extent, particularly in the fouthern parts of the county: the chief are hardware articles, nails, glafs, toys, japanned goods, and potters' ware; with productions in cotton, filk, leather, woollen, and linen. The manufacture of glafs is moft confiderable in the vicinity of Stourbridge, where many fpacious glafs-houfes have been built. The potteries occupy an extent of ten miles, toward the north part of the county: thefe have acquired great reputation from the ingenious Mr. Wedgewood. (See POTTERIES.) Wolverhampton and the neighbouring villages are diftinguifhed for the manufacture of locks: buckles, fteel-toys, and watch-chains, are among the efteemed productions of that town. The ftaple manufacture of Walfall and its vicinity is chiefly fhoe-buckles, clafps, and fadlers' ironmongery. Nail-making, in many country parifhes, is a fource of employment to great numbers of men, women, and children. Bilfton furnifhes a variety of plated, lackered, japanned, and enamelled goods. At Wednefbury the gun-trade is extenfive. At Darlafton, Willenhall, and the adjacent villages, tobacco and fnuff-boxes are wrought in various modes. Stafford and its neighbourhood exhibit numerous articles in the cutlery and leather-trade: the hat manufacture is alfo carried on there, and in fome other towns, on an extenfive fcale. Tin and brafs are among the common production of the county. The cotton manufactures at Roceller, Fazeley, Tamworth, Burton, and Tutbury, are very confiderable; as is likewife the filk-trade of Leek, and that of tape at Cheadle and Teyn. The woollen manufacture is but comparatively trifling; moft of the raw wool being fold into the clothing and ftocking diftricts. The making of linen is moftly confined to private families, for their own ufe.

It is worthy of obfervation, that the original wooden almanac of the Norwegians and Danes is ftill in ufe in this county, under the appellation of the Staffordfhire clogg. Engravings of this calendar, fomething different from each other, may be feen in Dr. Plot's Natural Hiftory of the County, and in Camden's Britannia, by Gough. The principal antiquities in this county are the cathedral at Lichfield; Tutbury caftle and church; Dudley caftle and priory; Ecclefhall caftle; Croxton abbey; Alton caftle; Wolverhampton church; bridge and abbey, at Burton-upon-Trent; Darlefton caftle; Tixal manor-houfe; Hilton abbey; Rowton priory; Uttoxeter church; Carefwell caftle; Chartley caftle; Heyley caftle.

Authorities.—Hiftory, &c. of Staffordfhire, by the Rev. S. Shaw, 2 vols. folio, 1798, &c. an unfinifhed work. General View of the Agriculture of the County of Stafford, by William Pitt, 8vo. 1808. The Natural Hiftory

of Staffordſhire, by Dr. Plot, fol. 1686. A Map of the County, begun in 1769, and finiſhed in 1775, by William Gates, ſix ſheets. Account of Staffordſhire, in the Beauties of England, vol. xiii.

Starch

STARCH, a ſubſtance which is extracted from wheaten flour, by waſhing it in water. All farinaceous ſeeds, and the roots of moſt vegetables, afford this ſubſtance in a greater or leſs degree; but it is moſt eaſily obtained from the flour of wheat, by moiſtening any quantity thereof with a little water, and kneading it with the hand into a tough paſte: this being waſhed with water, by letting fall upon it a very ſlender ſtream, the water will be rendered turbid as it runs off, in conſequence of the fecula or ſtarch which it extracts from the flour, and which will ſubſide when the water is allowed to ſtand at reſt. The reſiduum of the flour, which remains after the water has extracted all the fecula, and runs off colourleſs, will be found to be *gluten;* which ſee.

The ſtarch ſo obtained, when dried in the ſun, or by a ſtove, is uſually concreted into ſmall maſſes of a long figure and columnar ſhape, which have a fine white colour, ſcarcely any ſmell, and very little taſte. If kept dry, ſtarch in this ſtate continues a long time uninjured, although expoſed to the air. It is not ſoluble in cold water; but forms a thick paſte with boiling-hot water, and when this paſte is allowed to cool, it becomes ſemitranſparent and gelatinous, and being dried, becomes brittle, and ſomewhat reſembles gum.

Starch, although found in all nutritive grains, is only perfect when they have attained maturity, for before this it is in a ſtate approaching to mucilage, and ſo mixed with ſaccharine matter and eſſential oils, that it cannot be extracted in ſufficient purity to concrete into maſſes.

Wheat, or ſuch parts of it as are not uſed for human food, are uſually employed for manufacturing ſtarch, ſuch as the refuſe wheat and bran; but when the fineſt ſtarch is required, good grain muſt be uſed. This, being well cleaned, and ſometimes coarſely bruiſed, is put into wooden veſſels full of water to ferment: to aſſiſt the fermentation, the veſſels are expoſed to the greateſt heat of the ſun, and the water is changed twice a day, during eight or twelve days, according to the ſeaſon. When the grain burſts eaſily under the finger, and gives out a milky white liquor when ſqueezed, it is judged to be ſufficiently ſoftened and fermented. In this ſtate, the grains are taken out of the water by a ſieve, and put into a canvas ſack, and the huſks are ſeparated and rubbed off, by beating and rubbing the ſack upon a plank: the ſack is then put into a tub filled with cold water, and trodden or beaten till the water becomes milky and turbid, from the ſtarch which it takes up from the grain. A ſcum ſometimes ſwims upon the ſurface of the water, which muſt be carefully removed; the water is then run off through a fine ſieve into a ſettling-veſſel, and freſh water is poured upon the grains, two or three times, till it will not extract any more ſtarch, or become coloured by the grain. The water in the ſettling-veſſels being left at reſt, precipitates the ſtarch which it held ſuſpended; and to get rid of the ſaccharine matter, which was alſo diſſolved by the water, the veſſels are expoſed to the ſun, which ſoon produces the acetous fermentation, and takes up ſuch matter as renders the ſtarch more pure and white. During this proceſs, the ſtarch for ſale in the ſhops receives its colour, which conſiſts of ſmalt mixed with water and a ſmall quantity of alum, and is thoroughly incorporated with the ſtarch; but this ſtarch is unfit for medicinal purpoſes. When the water becomes completely ſour, it is poured gently off from the ſtarch, which is waſhed ſeveral times afterwards with clean water, and at laſt is placed to drain upon linen cloths ſupported by hurdles, and the water drips through, leaving the ſtarch upon the cloths, in which it is preſſed or wrung, to extract as much as poſſible of the water; and the remainder is evaporated, by cutting the ſtarch into pieces, which are laid up in airy places, upon a floor of plaſter or of ſlightly burnt bricks, until it becomes completely dried from all moiſture, partly by the acceſs of

warm air, and partly by the floor imbibing the moisture. In winter-time, the heat of a stove must be employed to effect the drying. Lastly, the pieces of dried starch are scraped, to remove the outside crust, which makes inferior starch, and these pieces are broken into smaller pieces for sale.

The grain which remains in the sack after the starch is extracted, contains the husks and the glutinous part of the wheat, which are found very nutritious food for cattle.

The French manufacturers, according to Les Arts et Metiers, pursue a more economical method, as they are enabled, by employing an acid water for the fermentation in the first instance, to use the most inferior wheat, and the bran or husks of wheat. This water they prepare, by putting a pailful of warm water into a tub, with about two pounds of leaven, such as some bakers use to make their dough rise or ferment. The water stands two days, and is then stirred up, and half a pailful of warm water added to it; then being left to settle till it is clear, it is poured off for use. To use this water in the fermentation of the materials, a quantity of it is poured into a tub, and about as much fair water is poured upon it as will fill the tub half full: the remainder of the tub is then filled up with the materials, which are one half refuse wheat, and the other half bran. In this tub it continues to steep and ferment during ten days, or less, according to the strength of the leaven-water, and according to the disposition of the weather for fermentation. When the materials have been sufficiently steeped, or fermented, an unctuous matter, which is the oil of the grain, will be seen swimming on the surface, having been thrown up by the fermentation. This must be scummed off; and the fermented grain, being taken out of the tub, is put into a fine hair-sieve, placed over a settling-tub, when fair water is poured upon it, and washed through the sieve into the tub; by which means the starch is carried through the sieve with the water, of which about six times the quantity of the grain are used.

The water stands in the settling-tub for a day, and becomes clear at top; when it is carefully laded out of the tub, leaving at the bottom a white sediment, which is the starch. The water which is taken off is sour, and is called *sure* water: this is the proper leaven for the first steeping of the materials. The starch now obtained must be rendered marketable; for which purpose, as much water is poured upon it as will enable it to be pounded and broken up with a shovel, and then the tub is filled up with fair water. Two days after this, the water is laded out from the tub, and the starch appears in the bottom, but covered over with a dark-coloured and inferior kind of starch, which is taken off, and employed for fattening hogs. The remainder of the sediment, which is good starch, is washed several times, to remove all the inferior starch; and when this is done, about four inches of thick starch should be found at the bottom of each tub: but the quantity varies, according to the goodness of the meal or bran which has been used. It is evident that the refuse wheat, when employed for making starch, ought to afford more, the whole being used, than the bran or husks; but the starch so extracted is always of an inferior quality to that which is extracted from the bran of good wheat, particularly in the whiteness of its colour. The starch in the different tubs is brought together into one, and there worked up with as much water as will dissolve it into a thin paste, which is put into a silk sieve, and strained through with fresh water. This water is settled in a tub, and afterwards poured off, but before it is so completely settled as to lose all its white colour: this renders the starch which is deposited still finer and whiter, and the starch which is deposited by the water so poured off is of a more common quality.

The starch thus purified is taken out of the bottom of the tubs, and put into wicker-baskets, about 18 inches long and 10 deep, rounded at the corners, and lined with linen cloths, which are not fastened to the baskets. The water drips from the starch through the cloths for a day, and the baskets are then carried up to apartments at the top of the house, where the floor is made of very clean white plaster; and the windows are thrown open, to admit a current of air. Here the baskets are turned downwards upon the plaster-floor, and the linen cloths, not being fastened to the baskets, follow the starch, and, when taken off, leave loaves, or cakes of starch, which are left to dry a little, and are then broken into smaller pieces, and left on the plaster-floor till very dry. But if the weather is at all humid, the starch is removed from the plaster-floor, and spread out upon shelves, in an apartment which is warmed by a stove, and there it remains till perfectly dry. The pieces are afterwards scraped, to remove the outside crust, which makes common starch; and the scraped pieces being again broken small, the starch is carried to the stove, and spread out to a depth of three inches, on hurdles covered with cloths. The starch must be turned over every morning and evening, to prevent it from turning to a greenish colour, which it would otherwise do.

Those manufacturers who are not provided with a stove, make use of the top of a baker's oven to spread the starch upon; and after being thoroughly dried here, it is ready for sale.

Starch may be made from potatoes, by soaking them about an hour in water, and taking off their roots and fibres, then rubbing them quite clean by a strong brush: after this they are reduced to a pulp, by grating them in water. This pulp is to be collected in a tub, and mixed up with a large quantity of clear water: at the same time, another clean tub must be provided; and a hair-sieve, not too fine, must be supported over it by two wooden rails extended across the tub. The pulp and water are thrown into the sieve, and the flour or starch is carried through with the water; fresh water must then be poured on, till it runs through quite clear. The refuse pulp which remains in the sieve, being boiled in water, makes an excellent food for animals; and the quantity of this pulp is near seven-eighths of all the potatoes employed.

The liquor which has passed through the sieve is turbid, and of a darkish colour, from the extractive matter which is dissolved in it. When it is suffered to rest for five or six hours, all this matter deposits or settles to the bottom, and the liquor which remains is to be poured off as useless; and a large quantity of fresh water is thrown upon the flour, and stirred up: it is then settled for a day, and the water being poured off, the flour will be found to have again settled in a whiter state. But to improve it, another quantity of water is poured on, and mixed up with it; in which state it is passed through a fine silk-sieve, to arrest any small quantity of the pulp which may have escaped the first hair-sieve. The whole must afterwards be suffered to stand quiet, till the flour is entirely settled, and the water above become perfectly clear; but if the water has any sensible colour or taste, the flour must be washed again with fresh water, for it is absolutely necessary that none of the extractive matter be suffered to remain with it. The flour, when thus obtained pure, and drained from the water, may be taken out of the tub with a wooden shovel, and placed upon wicker-frames covered with paper, to be dried in some situation properly defended from dust.

When the manufacture of starch from potatoes is attempted in a large way, some kind of mill must be used to

reduce them to a pulp, as the grating of them by hand is too tedious an operation. A mill invented by M. Baumé is very complete for this purpofe. In its general ftructure it refembles a large coffee-mill: the grater confifts of a cone of iron-plate, about feven inches in diameter, and eight inches in height, the exterior furface of which is made toothed, like a rafp, by piercing holes through the plate from the infide. This cone is fixed upon a vertical axle, with a handle at the top to turn it by; and is mounted on the pivots of the axle, within a hollow cylinder of plate-iron, toothed withinfide like the outfide of the cone; the fmalleft end of the interior cone being uppermoft, and the lower or larger end being as large as the interior diameter of the hollow cylinder. A conical hopper is fixed to the hollow cylinder, round the top of it, into which the potatoes are thrown; and falling down into the fpace between the outfide of the cone and the infide of the hollow cylinder, they are ground, and reduced to a pulp, when the interior cone is turned round by its handle; and as the lower part of the cone is fitted clofe to the interior diameter of the cylinder, the potatoes muft be ground to a fine pulp before they can pafs through between the two. The machine, when at work, is placed in a tub filled with water; and as faft as the grinding proceeds, the pulp mixes regularly with the water, ready for the procefs before defcribed.

Mr. Whately of Cork has alfo propofed a mill for the fame purpofe, on a different plan. The grater is a cylinder, with its axis horizontal, and turned by a handle at one end, with a fly-wheel to regulate the motion. A hopper is placed over the cylinder, into which the potatoes are thrown, and are grated by refting upon the cylinder, as it revolves round. There is alfo an horizontal box oppofite to the cylinder, into which the potatoes are received from the hopper, through a fliding-door; and a moveable end, which is fitted to the box, is preffed forwards towards the cylinder by a lever and weight, fo as to force the potatoes contained in the box againft the cylinder, which, being kept in conftant motion, grates away the potatoes into a pulp with great rapidity, and it falls into a box beneath.

In the year 1796, lord William Murray obtained a patent for manufacturing ftarch from horfe-chefnuts. The method was to take the horfe-chefnuts out of the outward green prickly hufk, and either by hand, with a knife or tool, or elfe with a mill adapted for the purpofe, the brown rind was carefully removed, leaving the chefnuts perfectly white, and without the fmalleft fpeck. In this ftate the nuts were rafped or ground to a pulp with water, and the pulp wafhed with water through a coarfe horfe-hair fieve, and twice afterwards through finer fieves, with a conftant addition of clear cold water, till all the ftarch was wafhed clean from the pulp which remained in the fieve; and the water being fettled, depofited the ftarch, which was afterwards repeatedly wafhed, purified, and dried, in the fame manner as the potatoe-ftarch before defcribed. We are not informed if this manufacture has been carried into effect.

The four, naufeous, milky liquor obtained in the procefs of ftarch-making, appears, upon analyfis, to contain acetous acid, ammonia, alcohol, gluten, and phofphate of lime. The office of the acid is to diffolve the gluten and phofphate of lime, and thus to feparate them from the ftarch.

Starch is ufed along with fmalt, or ftone-blue, to ftiffen and clear linen. The powder of it is alfo ufed to whiten and powder the hair.

It is alfo ufed by the dyers, to difpofe their ftuffs to take colours the better.

Starch is fometimes ufed inftead of fugar-candy for mixing with the colours that are ufed in ftrong gum-water, to make them work more freely, and to prevent their cracking. It is alfo ufed medicinally for the fame intentions with the vifcous fubftance which the flour of wheat forms with milk, in fluxes and catarrhs, under various forms of powders, mixtures, &c. A drachm of ftarch, with three ounces of any agreeable fimple water, and a little fugar, compofe an elegant jelly, of which a fpoonful may be taken every hour or two. Thefe gelatinous mixtures are likewife an ufeful injection in fome diarrhœas, particularly where the lower inteftines have their natural mucus abraded by the flux, or are conftantly irritated by the acrimony of the matter. Starch is the common vehicle for the exhibition of opium per anum.

By 43 Geo. III. c. 68. fched. (A), upon every hundred weight of ftarch imported a duty is impofed; and by 49 Geo. III. c. 98. fched. (A), a further duty upon every hundred weight is impofed.

No perfon fhall be a maker of ftarch within the limits of the head-office of excife in London, unlefs he occupies a tenement of 10*l.* a year, or upwards, for which he fhall be affeffed in his own name, and alfo pay to the poor-rates; nor elfewhere, unlefs he pay to the church and poor; or if there are no fuch rates, to the rate on houfes and windows, under the fame penalty as for making ftarch without entry. (19 Geo. III. c. 40. f. 3. 26 Geo. III. c. 51. f. 20.) By 43 Geo. III. c. 69. fched. (A), every ftarch-maker fhall take out a licence, for which he fhall pay 5*l.*, and renew the fame annually within ten days before the end of the year, on pain of 50*l.* 24 Geo. III. c. 41. feff. 2.

Places of making ftarch are to be entered, under penalty of 200*l.* (24 Geo. III. c. 48. feff. 2.) All rooms and places, veffels and utenfils, fhall be marked and numbered, on the penalty of 50*l.* (19 Geo. III. c. 40. f. 12.) Flour, and other materials, found in any private place, and all private utenfils and veffels for making or keeping ftarch, unentered, fhall be forfeited, or their value. (10 Ann. c. 26. f. 22.) Every ftarch-maker fhall caufe his *name* to be painted over his door, or on fome confpicuous part of the front of his houfe, with the addition of *ftarch-maker*, on penalty of 100*l.* (24 Geo. III. c. 48. feff. 2.) Officers may at all times enter and furvey, and make return to the commiffioners, leaving a true copy of the quantity, if demanded, under his hand, with the maker; and if he leave not fuch copy, after it has been demanded in writing (12 Geo. I. c. 28.), he fhall forfeit 40*s.* (10 Ann. c. 26. f. 14.) Notice of emptying the vats, and of taking the waters out of the tubs, fhall be given, on pain of forfeiting 100*l.* (19 Geo. III. c. 40.) The maker fhall ufe regular, fquare, or oblong boxes only, for boxing and draining his green ftarch, before it is dried in the ftove, on pain of 10*l.*; and give notice of boxing, and an account of drying, &c. Nor fhall he remove any ftarch after it is dried, before it be weighed, &c. by the officers, on pain of 200*l.* (4 Geo. II. c. 14. 19 Geo. III. c. 40.) All ftarch, before it be put into any ftove or place to dry (except for crufting), fhall be put in papers, tied up with ftrings, pafted over with a piece of paper of a different colour, and ftamped by the officer, under penalty of 100*l.* (26 Geo. III. c. 51.) Forging or ufing forged ftamps incurs a forfeiture of 500*l.* (26 Geo. III. c. 51.) The maker fhall have juft fcales and weights, on pain of 10*l.*; and if he fhall ufe infufficient fcales or weights, he fhall forfeit 100*l.* (10 Geo. III. c. 44.) Removing ftarch before due notice is prohibited by 10 Ann. c. 26. f. 19. And if it be removed before it is weighed by the officers, the perfon fo offending fhall forfeit 200*l.* (19 Geo. III. c. 40.) And if any dealer in ftarch fhall receive more than 28 lbs. not duly marked, he fhall forfeit 200*l.* 24 Geo. III. c. 48. 10 Ann. c. 26. f. 16.

Clandeftine manufacture, or concealing of ftarch, expofes the party concerned, unlefs he can make it appear that the

 duty

duty has been paid, to a forfeiture of 50*l.*: and obstructing the officer in entering, seizing, &c. the same, incurs a forfeiture of 100*l.* (4 Geo. II. c. 14. 23 Geo. II. c. 21.) And by 19 Geo. III. c. 40. if the maker shall conceal any starch, with intent to defraud his majesty of the duties, he shall forfeit 100*l.* Weekly entry shall be made, on pain of 50*l.*; and the duties shall be cleared within one week after entry, on pain of double duty. No starch shall be imported, except in packages containing at least 224 lbs., on pain of forfeiture, and of 50*l.* from the master of the vessel. (42 Geo III. c. 93.) Starch that hath paid the duties may be exported with a drawback of the duties. (10 Ann. c. 26. 27 Geo. III. c. 13.) The officers of excise or customs may seize any starch or hair-powder, with the horse and package, suspected on good reason to have been privily made, or imported without payment of duty, or relanded after drawback; and if the party doth not make it appear that the duty hath been paid, they shall all be forfeited, with an additional forfeiture of 5*l.* for every hundred weight. (4 Geo. II. c. 14.) If any person shall knowingly harbour or conceal any starch unlawfully imported, or relanded after shipping for exportation upon debenture, he shall, whether he claim any property in it or not, forfeit 50*l.* for every hundred weight, together with the goods and package. (23 Geo. II. c. 21.) No perfumer, &c. shall make use of, or offer to sale, any hair-powder made of or mixed with alabaster, talc, plaster of Paris, whiting, lime, &c. (sweet scents only excepted), on pain of forfeiting the same, and 50*l.* (12 Ann. stat. 2. c. 9.) And if any maker of hair-powder shall mix any powder of alabaster, &c. (rice first made into starch, and sweet scents only excepted), he shall forfeit the same, and 50*l.* (12 Ann. stat. 2. c. 9.) Or if any one make or sell any made with such materials, he shall forfeit the same, and 20*l.* (4 Geo. II. c. 14.) Or if he shall have in his possession, for making, mixing, or counterfeiting hair-powder, any materials besides starch, or powder of starch, or rice made into starch, he shall forfeit the same, and 10*l.* Places for making hair-powder are to be entered, and officers may enter and survey them, under a penalty of 20*l.* 4 Geo. II. c. 14.

Every maker of stone-blue for sale shall make entry of his name, place of abode, place of manufacture and keeping, and materials, on pain of 50*l.* (26 Geo. III. c. 51.) Officers may enter and survey without obstruction, under penalty of 50*l.*: nor shall any flour, meal, or other ingredients (other than for colouring the same), be used, except starch for which the duties have been paid, on pain of forfeiting the same and 100*l.*

Nor shall any maker of stone-blue or hair-powder for sale receive into his possession any starch in papers not stamped, under pain of forfeiting 10*s.* a pound, together with the same: and if any maker shall keep above 28 lbs. of starch or hair-powder in any unentered place, the same shall be forfeited and also 50*l.* 26 Geo. III. c. 51.

All the preceding forfeitures shall be sued for, levied, and mitigated, as by the laws of excise, or in the courts at Westminster; and be distributed, half to the king and half to the prosecutor.

STARCHY *Matter of Roots, Plants, and Seeds*, in *Rural Economy*, is a material which forms a principal part of a great number of esculent articles of different kinds, upon which their nutrient properties and qualities probably in a great measure depend when used as the food of man, or employed in the feeding and fattening of several different kinds of domestic animals. See STARCH.

Thus, it is ascertained to exist in considerable quantities in the root of the potatoe and some other roots, in many different plants of the edible kind, and to constitute the greatest part of most grains, pulse, and seeds which are employed as food. It is met with in a large proportion in the different nourishing vegetable substances which are known and made use of under the names of sago, salep, arrow-root, tapioca, cassava, and some others. In regard to the roots, plants, and perhaps seeds, derived from weeds, it is known to abound much in the root of *arum maculatum*, or wake robin, of the wild or English hyacinth, of white bryony, of meadow saffron, and of a variety of others. It is very predominant in numerous wild plants, and most probably in most of their seeds.

Sir Humphrey Davy conceives, that this matter or coagulated mucilage, which forms the greatest part of all grains and seeds which are used in the way of food, is generally combined with gluten, oil, or albuminous matter. In corn, with gluten; in pulse, such as peas and beans, with albuminous matter; and in rape-seed, lint-seed, hemp-seed, and the kernels of most nuts, with oils. He found that one hundred parts of good full-grained wheat sown in the autumn, afforded seventy parts of starch and nineteen parts of gluten: that one hundred parts of wheat sown in the spring yielded seventy of starch and twenty-four of gluten: that the same number of parts of Barbary wheat gave seventy-four of starch and twenty-eight of gluten: and that an equal number of parts of Sicilian wheat afforded seventy-five of starch and twenty-one of gluten. He has also tried different specimens of North American wheat, all of which have contained rather more gluten than those of British growth. In general, it is said, the wheat of warm climates abounds more in gluten and insoluble parts; and is of greater specific gravity, harder, and more difficult to grind, than that of others: and that the wheat of the south of Europe, in consequence of containing a larger proportion of gluten, is peculiarly fitted for making macaroni, and preparations of flour in which a glutinous quality is considered as an excellence.

In some trials made on barley, he obtained, from one hundred parts of a full, fair, Norfolk sort, seventy-nine of starch, six of gluten, and eight of husk; the remaining seven parts consisting of sweet or saccharine matter. The sugar in barley is suggested as probably the chief cause why it is more proper for malting than any of the other sorts of grain. It is stated that Einhoff, in his minute trials on barley-meal, found in three thousand eight hundred and forty parts, three hundred and sixty of volatile matter, forty-four of albumen, two hundred of saccharine matter, one hundred and seventy of mucilage, nine of phosphate of lime, with some albumen, one hundred and thirty-five of gluten, two hundred and sixty of husk, with some gluten and starch, two thousand five hundred and eighty of starch not quite free from gluten, and seventy-eight parts of loss in the whole. And that rye afforded to the same experimenter, in the same number of parts, two thousand five hundred and twenty of meal, nine hundred and thirty of husk, and three hundred and ninety of moisture: the same quantity of meal, on being analysed, gave two thousand three hundred and forty-five of starch, one hundred and twenty-six of albumen, four hundred and twenty-six of mucilage, one hundred and twenty-six of saccharine matter, and three hundred and sixty-four of gluten not dried. The remainder husk and loss.

The first of these writers obtained from one thousand parts of rye, which was grown in Suffolk, sixty-one parts of starch and five of gluten.

One hundred parts of oats, from Sussex, afforded him fifty-nine parts of starch, six of gluten, and two of saccharine matter.

One thousand parts of peas, grown in Norfolk, also afforded

forded him five hundred and one parts of ſtarch, twenty-two of ſaccharine matter, thirty-five of albuminous matter, and ſixteen parts of extract, which became inſoluble during the evaporation of the ſaccharine fluid.

From three thouſand eight hundred and forty parts of marſh beans, (*vicia faba,*) the latter writer is ſtated to have obtained one thouſand three hundred and twelve of ſtarch, thirty-one of albumen, and one thouſand two hundred and four of other matters which may be conceived to be nutritive; ſuch as gummy, ſtarchy, fibrous matter, analogous to animal matter.

The ſame quantity of kidney-beans (*phaſeolus vulgaris*) is ſaid to have afforded him, one thouſand eight hundred and five parts of matter analogous to ſtarch, eight hundred and fifty-one of albumen and matter, approaching to animal matter in its nature, and ſeven hundred and ninety-nine of mucilage.

From the ſame number of parts of lentils he is alſo ſtated to have obtained one thouſand two hundred and ſixty parts of ſtarch, and one thouſand four hundred and thirty-three of a matter analogous to animal matter, which is deſcribed as a glutinous ſubſtance inſoluble in water; but ſoluble in alcohol when dry, having the appearance of glue; probably, it is ſuppoſed, a peculiar modification of gluten.

Different tuberous, bulbous, and common roots contain a large portion of ſtarchy matter, but it probably abounds moſt in the potatoe. It is ſaid that theſe roots in general afford from one-fifth to one-ſeventh of their weight of dry ſtarch. And that from one hundred parts of the common kidney potatoe Dr. Pearſon obtained from twenty to twenty-three of ſtarch and mucilage: the ſame number of parts of the apple potatoe afforded ſir Humphrey Davy in various trials, from eighteen to twenty parts of pure ſtarch. From five pounds of ſeveral other different varieties, in the trials of another experimenter, from twelve to eight ounces and a quarter of ſtarch have been obtained. It is added, that from the analyſis of Einhoff, it appears that ſeven thouſand ſix hundred and eighty parts of potatoes afford one thouſand one hundred and fifty-three of ſtarch, five hundred and forty of fibrous matter analogous to ſtarch, one hundred and ſeven of albumen, three hundred and twelve of mucilage in the ſtate of a ſaturated ſolution: in the whole, two thouſand one hundred and twelve parts. So that a fourth part of the weight of the potatoe at leaſt may, it is ſaid, be conſidered as nutritive matter. Hence its very great utility as an article of food for man, and its great application in the feeding and fattening of animals.

The propriety of encouraging the production of ſtarch from uſeleſs roots, plants, and products, has been ſome time ſince ſuggeſted by Mr. Pitt in his Account of the Agriculture of Staffordſhire, and which is ſaid to equally apply to the preparation of this ſubſtance from any other vegetable which may not be a leading article of food, as well as to the production of hair-powder, paſte, and other articles generally made from wheat.

Steam

STEAM, in a general ſenſe, is a term uſed to ſignify the viſible cloudineſs ariſing from the condenſation of aqueous vapour.

In thoſe arts and manufactures where the vapour of water is employed, ſuch as ſteam-engines, the term ſteam is uſed for water in its elaſtic form, at or above the temperature of 212°, and when it is inviſible. It is in this form that we can properly call it ſteam; as we ſhall ſhew, that in the viſible miſty form in which we ſee it in the atmoſphere, both in the form of clouds, and as it paſſes from a warm medium into a colder one, it is not ſteam but water in minute globules.

Some have confined the word ſteam to the vapour of water not leſs than 212°, as if water did not aſſume the elaſtic form at a lower temperature; conceiving it to exert the full force of ſteam the moment it arrives at that point, and to be wholly converted into water when reduced below the ſame. Nothing, however, can be more abſurd than this notion: ſteam can exiſt at the loweſt known temperature. At 50° below the cypher of Fahrenheit, if the barometer could ſhew it, the preſence of ice would afford an elaſtic fluid of ſome force. We want no other proof of this fact than the experiments of different philoſophers to aſcertain the force of aqueous vapour, anſwering to different temperatures; and before we proceed further on our ſubject, it may not be amiſs to give the table of theſe facts, formed by Mr. John Dalton of Mancheſter. In order to make theſe experiments, Mr. Dalton took a barometer of the common ſize. The mercury was firſt boiled, to free it from air. He then put a little water into the tube, and poured it out again, leaving its ſides wet; and next introduced the mercury, inverting the tube ſo as to exclude the air. The water, being the lighteſt fluid, roſe above the ſurface of the mercury about one-eighth of an inch. He then ſurrounded the tube, from the top downwards, with another tube, 14 inches long and 2 inches diameter; forming a cavity between the tubes, capable of holding water of different temperatures. The temperature of this water was conſtantly marked by a thermometer placed in it; and the elaſticity of the vapour, in the upper part of the barometer, was conſtantly marked by the height of the mercury. The outer tube being of glaſs, the whole could be ſeen. This apparatus was uſed for all the temperatures below 155°. For the higher temperatures, as high as 212°, he uſed an outer tube of tin, with a ſiphon barometer.

Theſe reſults he found to agree with ſimilar experiments made with the air-pump. The air-pump was provided with a mercurial gage of conſiderable extent. Some water was firſt made to boil in a Florence flaſk, in which a thermometer was placed. In this ſtate it was put under the receiver, and then the air being withdrawn, the ſteam alone affected the barometer; the thermometer, at the ſame time, marking the temperature.

From theſe facts Mr. Dalton conſtructed his table. The altitudes of the mercury, anſwering to the degrees of temperature, he found not to have a conſtant ratio; nor did they vary by any regular progreſſion. When the degrees were in arithmetical progreſſion, the columns of mercury anſwering thereto were not in the ſame, but ſomething approaching to a geometrical ſeries. The increaſe, although not ſtrictly geometrical, of the ratios themſelves diminiſhed regularly, which enabled him to calculate with ſufficient exactneſs thoſe degrees which he could not aſcertain by experiment. We ſeldom find any of nature's laws attended with any thing ſo indefinite; and Mr. Dalton very properly obſerves, that the defect is not in nature, but in the imperfect ſcale of our thermometers, which, M. de Luc and others have ſhewn, do not mark equal increments of heat.

Table of the Force of Vapour from Water in every Temperature, from that of the Congelation of Mercury, or 40° below Zero of Fahrenheit, to 325°.

Temperature.	Force of Vapour in Inches of Mercury.	Weight of Vapour in a Cubic Foot of Space.	Temperature.	Force of Vapour in Inches of Mercury.	Weight of Vapour in a Cubic Foot of Space.	Temperature.	Force of Vapour in Inches of Mercury.	Weight of Vapour in a Cubic Foot of Space.
−40°	.013	.1096	49	.363	3.061	104	2.11	17.79
−30	.020	.1686	50	.375	3.162	105	2.18	18.79
−20	.030	.2530	51	.388	3.238	106	2.25	18.97
−10	.043	.3626	52	.401	3.457	107	2.32	19.55
—	—	—	53	.415	3.499	108	2.39	20.15
0	.064	.5397	54	.429	3.617	109	2.46	20.74
1	.066	.5566	55	.443	3.735	110	2.53	21.33
2	.068	.5734	56	.458	3.862	111	2.60	21.92
3	.071	.5987	57	.474	3.997	112	2.68	22.26
4	.074	.6274	58	.490	4.130	113	2.76	23.24
5	.076	.6409	59	.507	4.242	114	2.84	23.95
6	.079	.6666	60	.524	4.419	115	2.92	24.39
7	.082	.6915	61	.542	4.540	116	3.00	25.30
8	.085	.7168	62	.560	4.722	117	3.08	25.97
9	.087	.7337	63	.578	4.874	118	3.16	29.31
10	.090	.7590	64	.597	5.034	119	3.25	27.40
11	.093	.7843	65	.616	5.194	120	3.33	28.08
12	.096	.8096	66	.635	5.355	121	3.42	28.84
13	.100	.8433	67	.655	5.523	122	3.50	29.51
14	.104	.8773	68	.676	5.700	123	3.59	21.17
15	.108	.9114	69	.698	5.886	124	3.69	31.11
16	.112	.9445	70	.721	6.080	125	3.79	31.99
17	.116	.9782	71	.745	6.282	126	3.89	32.80
18	.120	1.120	72	.770	6.493	127	4.00	33.73
19	.124	1.457	73	.796	6.712	128	4.11	34.66
20	.129	1.878	74	.823	6.940	129	4.22	35.58
21	.134	1.130	75	.851	7.176	130	4.34	36.58
22	.139	1.172	76	.880	7.421	131	4.47	37.69
23	.144	1.214	77	.910	7.677	132	4.60	38.79
24	.150	1.265	78	.940	7.594	133	4.73	39.88
25	.156	1.315	79	.971	8.188	134	4.86	40.98
26	.162	1.366	80	1.00	8.466	135	5.00	42.16
27	.168	1.416	81	1.04	8.770	136	5.14	43.34
28	.174	1.467	82	1.07	9.023	137	5.29	44.61
29	.180	1.518	83	1.10	9.276	138	5.44	45.87
30	.186	1.568	84	1.14	9.614	139	5.59	47.14
31	.193	1.620	85	1.17	9.867	140	5.74	48.40
—	—	—	86	1.21	10.20	141	5.90	49.75
3	.200	1.686	87	1.24	10.45	142	6.05	50.31
33	.207	1.745	88	1.28	10.79	143	6.21	51.37
34	.214	1.804	89	1.32	11.13	144	6.37	53.72
35	.221	1.863	90	1.36	11.46	145	6.53	55.06
36	.229	1.931	91	1.40	11.80	146	6.70	56.53
37	.237	1.998	92	1.44	12.14	147	6.87	57.33
38	.245	2.066	93	1.48	12.48	148	7.05	59.45
39	.254	2.142	94	1.53	12.90	149	7.23	60.97
40	.263	2.217	95	1.58	13.32	150	7.42	62.57
41	.273	2.302	96	1.63	13.75	151	7.61	64.17
42	.283	2.353	97	1.68	14.16	152	7.81	65.86
43	.294	2.479	98	1.74	14.68	153	8.01	67.55
44	.305	2.572	99	1.80	15.18	154	8.20	69.15
45	.316	2.664	100	1.86	15.68	155	8.40	70.84
46	.328	2.762	101	1.92	16.19	156	8.60	72.52
47	.339	2.858	102	1.98	16.69	157	8.81	74.29
48	.351	2.960	103	2.04	17.20	158	9.02	76.06

TABLE—*continued.*

Temperature.	Force of Vapour in Inches of Mercury.	Weight of Vapour in a Cubic Foot of Space.	Temperature.	Force of Vapour in Inches of Mercury.	Weight of Vapour in a Cubic Foot of Space.	Temperature.	Force of Vapour in Inches of Mercury.	Weight of Vapour in a Cubic Foot of Space.
159	9.24	77.72	214	31.21	263.20	270	77.85	656.53
160	9.46	79.77	215	31.83	267.39	271	78.89	665.30
161	9.68	82.63	216	32.46	272.74	272	79.94	674.16
162	9.91	83.57	217	33.09	275.72	273	80.98	682.93
163	10.15	84.45	218	33.72	284.37	274	82.10	692.37
164	10.41	88.04	219	34.35	289.68	275	83.13	701.06
165	10.68	90.07	220	34.99	298.88	276	84.35	711.38
166	10.96	91.76	221	35.63	300.81	277	85.47	720.79
167	11.25	94.87	222	36.25	305.70	278	86.50	729.48
168	11.54	97.32	223	36.88	311.02	279	87.63	739.01
169	11.83	99.76	224	37.53	316.50	280	88.75	748.45
170	12.13	102.96	225	38.20	322.15	281	89.87	757.90
171	12.43	104.45	226	38.89	327.63	282	90 99	767.34
172	12.73	107.34	227	39.59	336.87	283	92.11	776.97
173	13.02	109.73	228	40.30	339.86	284	93.23	786.23
174	13.32	112.32	229	41.02	345.93	285	94.35	795.68
175	13.62	114.52	230	41.75	352.09	286	95.48	805.21
176	13.92	117.39	231	42.49	358.33	287	96.64	814.99
177	14.22	126.58	232	43.24	364.65	288	97.80	824.78
178	14.52	122.45	233	44.00	371.06	289	98.96	834.56
179	14.83	126.06	234	44.78	377.64	290	100.12	844.34
180	15.15	127.76	235	45.58	384.39	291	101.28	854.12
181	15.50	130.71	236	46.39	391.22	292	102.45	863.99
182	15.86	133.75	237	47.20	398.05	293	103.63	873.94
183	16.23	136.87	238	48.02	404.96	294	104.80	883.81
184	16.61	141.41	239	48.84	411.88	295	105.97	893.68
185	17.00	143.36	240	49.67	418.88	296	107.14	903.54
186	17.40	145.17	241	50.50	425.18	297	108.31	913.41
187	17.80	148.51	242	51.34	432.96	298	109.48	923.28
188	18.20	153.48	243	52.18	440.05	299	110.64	933.06
189	18.60	156.86	244	53.03	447.21	300	111.81	942 93
190	19.00	160.23	245	53.88	454.38	301	112.98	952.79
191	19.42	163.77	246	54.68	461.13	302	114.15	962.99
192	19.86	167.48	247	55.64	468.35	303	115.32	972.53
193	20.32	171.36	248	56.42	476.26	304	116.50	982.15
194	20.77	175.16	249	57.31	482.98	305	117.68	992.43
195	21.22	178.95	250	58.21	490.90	306	118.86	1002.38
196	21.68	182.83	251	59.12	491.91	307	120.05	1014.53
197	22.13	186.62	252	60.05	506.42	308	121.20	1020.12
198	22.69	186.62	253	61.00	514.43	309	122.37	1034.98
199	23.16	195.98	254	61 92	522.19	310	123.53	1041.76
200	23.64	199.36	255	62.85	530.33	311	124 69	1051.55
201	24.12	203.41	256	63.76	537.70	312	125.85	1061.36
202	24.61	207.54	257	64.82	579.98	313	127.00	1071.03
203	25.10	211.67	258	65.78	554.74	314	128.15	1080.73
204	25.61	219.31	259	66.75	562.92	315	129 29	1090.24
205	26.13	220.36	260	67.73	571.18	316	130.43	1099.95
206	26.66	224.83	261	68 72	579.53	317	131.57	1109.57
207	27.20	229.38	262	69.72	587.97	318	132.72	11.9.27
208	27.74	233.94	263	70.73	596.48	319	133.86	1125.55
209	28.20	237 82	264	71.74	605.00	320	135.00	1138.50
210	28.84	243.21	265	72.76	603.60	321	136.14	1148.11
211	29.41	248.02	266	73.77	617.06	322	137 28	1157 72
212	30 00	253.00	267	74 79	670.72	323	138.42	1167.34
——	——	——	268	75 80	679.24	324	139.56	1176 95
213	30.60	258 06	269	76.82	647.84	325	140 70	1186.57

In anſwer to ſome references which may be required, we have thought proper to add a third column to this table, ſhewing the weight of aqueous vapour contained in a cubic foot of ſpace, when a ſufficient quantity of water is preſent at the given temperature. This column has been formed on the fact, that when the force of vapour is 30 inches, the aqueous vapour in a cubic foot of ſpace is equal to 253 grains. And ſince the denſity muſt be as the preſſure; therefore, as 30 inches is to 253 grains, ſo is the force of vapour of any other degree to the number of grains in the cubic foot at the ſame.

This table, from 30° to 212°, was the reſult of careful experiment. Thoſe below and above were determined by calculation, and will doubtleſs be much more correct than by experiment, from the great difficulty and uncertainty which the high and low temperatures would occaſion. For a more detailed account of Mr. Dalton's experiments, ſee the Mancheſter Tranſactions, vol. v., and Nicholſon's Journal, vols. vi. and vii.

Theſe will be found a valuable reference in all practical applications of ſteam, and will not be of leſs importance in aſſiſting any inquiry into the proceſs of evaporation, as connected with the arts of life, and the natural evaporation in the air. With a view to aſſiſt our conception of the nature of ſteam, or of the elaſtic vapour of water, we ſhall condenſe a number of facts, which may be very proper to commit to memory.

1. A cubic inch of water forms a cubic foot of ſteam, when its elaſticity is equal to 30 inches of mercury.

2. One pound of Newcaſtle coal converts ſeven pounds of boiling water into ſteam.

3. The time required to convert a given quantity of boiling water into ſteam, is ſix times that required to raiſe it from the freezing to the boiling point, or from 32° to 212°, ſuppoſing the ſupply of heat to be uniform.

4. When a quantity of water is expoſed to a given temperature, the quantity of ſteam formed in a given time will be as the ſurface, all other things being equal. The quantity will alſo be jointly as the force of vapour anſwering to each degree of heat, and the ſurface.

The depth of water evaporated, in a given time, will be as the force of vapour, whatever the ſurface, if the maſs be uniformly of the ſame temperature.

When the force of vapour is 30 inches, and the temperature at 212°, this degree being juſt preſerved only, the depth evaporated is 1.3 inch in one hour. This will be near the truth for this temperature. For lower temperatures, the rules given with the table will point it out.

5. When a quantity of water is raiſed to the boiling point, or 212°, it requires as much heat to give it the elaſtic form as would raiſe the ſame water 900° higher. If its volume were not changed by the heat, that is, if it could be prevented from expanding, its temperature would become 1112°, with the ſame quantity of caloric. Thus, agreeably to fact the 3d, the heat required to convert water of 212° into ſteam, is ſix times that required to raiſe the temperature from 32° to 2 2°.

6. The ſame weight of water, in the form of ſteam, contains the ſame quantity of heat, whatever may be its temperature or denſity; that is, the temperature at which the ſteam is formed, added to the degrees required to give it the elaſtic form, is always a conſtant quantity. The meaning of this is, that if a given weight of aqueous vapour, at 100° for inſtance, were compreſſed till its elaſticity became equal to that at 212°, no heat being allowed to eſcape, its temperature would become 212° by the condenſation; and it would, of courſe, contain the ſame heat as ſteam formed at the ſame temperature, *viz.* 212 + 900, as mentioned in the laſt fact.

In viewing the ſecond column of the table, and comparing it with the temperature in the firſt column, we ſhall be far from concluding that all the ſteam in the cylinder of a ſteam-engine is condenſed by the beſt means employed. Owing to the circumſtance of the rapid decreaſe of the force of vapour from the boiling point, ſome have been led to imagine that there is no medium between ſteam at 212° and liquid water. By referring to the table, we ſhall ſee that, by a decreaſe of temperature from 212° to 180°, the column of 30 inches is reduced to 15. This column is again biſected or reduced to 7.5, by the temperature falling to 150°.5. At 124°.5, the ſteam exerts a force equal to 3.75 inches of mercury; and this will be reduced to 1.875, at the temperature of 100°.5.

We here ſee the importance of Mr. Watt's diſcovery of condenſing his ſteam in a ſeparate veſſel. The ſpring of the reſidual vapour in his cylinder, after condenſation, is only equal to the force of vapour anſwering to the temperature of his condenſer, while the cylinder itſelf is kept at 212° nearly.

In the old method of condenſing in the cylinder, ſo much cold water would be added as would reduce the temperature as low as Mr. Watt's condenſer, in order to produce as perfect a vacuum; and on filling the cylinder again the next time, it would require to be raiſed to its original heat, at the expence of freſh ſteam. The effect of cold water in condenſing ſteam, whether in the cylinder or a ſeparate veſſel, may be eaſily known by calculation, and the aid of the preceding table.

Let C = the capacity of the veſſel containing ſteam in cubic feet.
S = the weight of a cubic foot of ſteam.
q = the weight of condenſing water.
T = its temperature.
b = the degrees of heat to convert water into ſteam.
d = the temperature of the ſteam.
t = the reſulting temperature, ſuppoſing b and d to be ſenſible heat before the experiment, and t the ſame afterwards.
n = capacity of ſteam for heat, water being 1.

Then, according to a theorem for finding the reſulting temperature by mixing bodies of different temperatures together, $t = \frac{q\text{T} + (b+d)\text{CS}n}{q + \text{CS}n}$; t, in this, will come out as if the ſteam in the veſſel, after mixture, were condenſed into water; when, in fact, the heat is divided between the remaining ſteam and the water, one part giving the whole a common temperature, and the other in a latent form giving elaſticity to the vapour. But, according to fact the 6th, as before given, this ſteam contains as much heat above its own temperature as would raiſe it to 1112°: hence the real temperature added to the latent heat will be equal t.

The concluſion from theſe facts will be, that $\frac{b+d}{t}$ will be nearly in the ſame ratio with the denſity of the ſteam, before and after condenſation, and, therefore, as the reſpective force of vapour. If p be the force of vapour of the ſteam before the experiment, and f that after condenſation; then $\frac{b+d}{t} = \frac{p}{f}$, and $f = \frac{pt}{b+d}$. If we

now

now refer to the table with this force of vapour, we ſhall find the temperature after condenſation. To illuſtrate this theorem by an example,

Let C = 1 cubic foot.
S = 253 grains, the weight of a cubic foot of ſteam.
q = 253 grains of water.
T = 60.
h = 900.
d = 212.

$$t = \frac{q\mathrm{T} + (h + d)\,\mathrm{SC}n}{q + \mathrm{CS}n} =$$

$$\frac{253 \times 60 + (900^\circ + 212^\circ) \times 253 \times 9}{253 + 253 \times \cdot 9} = 558.$$

Then $\frac{h + d}{t} = \frac{p}{f}$, or $\frac{1112}{558} = \frac{30}{f}$ $\therefore f = 15$ inches of mercury. Now, the temperature anſwering to this force of vapour, in the table, is equal to 177°.5. The quantity of ſteam of this denſity will be as p to f; therefore, as 30 : 15 :: 253 : 126.5 grains: hence the whole weight, which was 558 − 126.5, = 431.3 grains, the weight of water. Hence, if the capacity of the ſteam-veſſel be known, and the degree of condenſation at the ſame time be given, the ſupply of cold water for that purpoſe may be aſcertained. This will be $q = \frac{h + d - t}{t - \mathrm{T}}\,\mathrm{CS}\,n.$

We have before hinted at the vulgar idea of there being no medium between ſteam at 212° and liquid water. A doctrine ſtrongly favourable to ſuch an opinion is at preſent held by ſeveral philoſophers of eminence. The elaſtic form of water, at all temperatures below 212°, is ſuppoſed to be a ſolution of water in air. Does any thing like this appear to be the caſe in the detail of Mr. Dalton's experiments, to determine the force of vapour of ſteam at different temperatures? We would aſk, where was the air to diſſolve the water above the column of mercury, in which water and mercury alone exiſted? It is admitted on all hands, that ſteam at 212° can exiſt independent of air; and where have we become acquainted with any rule, that aqueous vapour cannot exiſt in a ſeparate ſtate at other temperatures? This is certainly the caſe with reſpect to water; and it is highly probable, that a portion of all the ſolid and liquid matter on the globe exiſts in the elaſtic form, in proportion to the temperature. What is the ſmell we perceive from melted metals, and at a much lower temperature with ſome of the metals? This is very conſpicuouſly obſerved in heating copper-plates and ſheet-lead. The odour of caſt-iron is particularly ſtriking.

There can be no doubt that elaſtic mercury exiſts in the ſpace above the mercury in a barometer, ſince the condenſed mercury is ſeen frequently to coat the interior ſurface.

Theſe appearances would be oftener obſerved, if it were not for the difficulty with which evaporation takes place, from the body affording the vapour being ſurrounded with vapour of its own and others. The preſence of any elaſtic fluid mechanically reſiſts further evaporation, to a degree more than is conceived. If water be expoſed to a vacuum, a quantity of vapour depending upon the temperature would in a little time occupy the ſpace; the firſt portion would project itſelf with great rapidity, and the laſt very ſlowly. The temperature being raiſed, would cauſe ſucceſſive portions to riſe, the limit being what we have ſhewn in the table. If at any temperature the vapour, already ſuſpended over the water, be removed by a current or by an air-pump, the proceſs would be greatly facilitated, as we obſerve in the drying of the ground in a briſk wind. This ſhews that the vapour of water reſiſts evaporation more than the air itſelf; perhaps in the ſame medium, its retarding power increaſes as the denſity. The advocates for the ſolution of water in air have ſaid, that the capacity of air for moiſture is inverſely as the denſity, whether this difference of denſity ariſes from the nature of the gas, or from rarefaction. It ought very properly to be aſked, at what degree of rarefaction is the diſſolved water a maximum? The moſt probable anſwer would be, at the limit of rarefaction. This is contrary to all laws of ſolution. If air can chemically combine with water, every particle of air may combine with a particle of water; and the quantity of water in a given ſpace would be the greateſt, when the air was the denſeſt. If we had no direct proof that a given ſpace will contain the ſame quantity of water, whether air be preſent or not, the hypotheſis of the chemical ſolution of water in air could not be defended.

We have ſeen that the quantity of water in a given ſpace is as the force of vapour in inches of mercury, becauſe the denſity muſt be as the preſſure. Mr. Dalton has aſcertained by experiment, that the rate of evaporation, at a given temperature, is as the force of vapour at the ſame. See Nicholſon's Journal, vol. vii. p. 5.

This fact leads to the concluſion, that ſince the denſity is alſo as the force of vapour, the velocity of diſperſion through the air is the ſame at all temperatures. Since, however, the atmoſphere always contains ſome moiſture, the neat evaporating power will be as the difference between that force of vapour anſwering to the temperature at which dew would begin to fall, and the temperature to which the evaporating ſubſtance is expoſed. That point in the atmoſphere when dew falls, is called by Mr. Dalton the *dew-point*. The manner of finding this is as follows: Take a tall cylindrical bottle, about one foot high and three inches in diameter; or, if this is not at hand, a common decanter. Fill it with water ſo much colder than the air, that the bottle may appear miſty, when it is put into it. If no appearance of this miſt is obſerved, the water is not cold enough; and ice, or ſome freezing mixture, muſt be added to it. The bottle, when filled, muſt contain a thermometer. When the dew appears upon it, wipe it off with a clean dry cloth; and continue to do ſo till no more dew appears. Then obſerve at what degree the thermometer ſtands in the bottle, which will never be greater than the temperature of the air, which muſt alſo be noted. Then find in the table the force of vapour at the temperature of the dew-point, and alſo the force of vapour anſwering to the temperature of the atmoſphere, or that of the maſs which is the ſource of the vapour. The difference between theſe two columns of mercury will be expreſſive of the rate of evaporation.

In order to obtain abſolute data for theſe proceſſes, we ſhall make uſe of Mr. Dalton's facts, which were derived from careful and judicious experiments. He expoſed water to different temperatures, to obſerve the weight evaporated in a given time. Theſe veſſels were of a cylindric form, one being 3¼ inches in diameter, and the other ſix inches. The leſſer veſſel, when the water in it was juſt made to boil, loſt from 35 to 45 grains *per* minute; this difference being occaſioned by a greater or leſſer current of air paſſing over it. The quantities evaporated at different temperatures were found to agree exactly with the force of vapour.

From a veſſel of ſix inches in diameter, he found that at 212° the mean quantity evaporated in one minute was 154 grains. Then ſince the mean of the ſmall veſſel was about 40, if the quantity be as the ſurface, we ought to have $\frac{154}{40} = \frac{(6)^2}{(3.25)^2}$, which is very near; for if the ſmall veſſel had been 3.05, then the two ſquares would have been in the ratio of $\frac{154}{40}$.

Mr. Dalton has conſtructed a table on theſe data, which, from its great utility in all inquiries relating to the moiſture in the atmoſphere, cannot fail to be acceptable.

Table, ſhewing the Force of Vapour, and the full evaporating Force for every Degree of Temperature from 20° to 85°, expreſſed in Grains of Water raiſed *per* Minute, ſuppoſing no Moiſture in the Atmoſphere at the Time.

	Force of Vapour.	Evaporating Force in Grains per Minute. Leſſer Extreme.	Mean.	Greater Extreme.
212°	30	120	154	189
20	.129	.52	.67	.82
21	.134	.54	.69	.86
22	.139	.56	.71	.88
23	.144	.58	.73	.91
24	.150	.60	.77	.94
25	.156	.62	.79	.97
26	.162	.65	.82	1.02
27	.168	.67	.86	1.05
28	.174	.70	.90	1.10
29	.180	.72	.93	1.13
30	.186	.74	.95	1.17
31	.193	.77	.99	1.21
32	.200	.80	1.03	1.26
33	.207	.83	1.07	1.30
34	.214	.86	1.11	1.35
35	.221	.90	1.14	1.39
36	.229	.92	1.18	1.45
37	.237	.95	1.22	1.49
38	.245	.98	1.26	1.54
39	.254	1.02	1.31	1.60
40	.263	1.05	1.35	1.65
41	.273	1.09	1.40	1.71
42	.283	1.13	1.45	1.78
43	.294	1.18	1.51	1.85
44	305	1.22	1.57	1.92
45	316	1.26	1.62	1.99
46	327	1.31	1.68	2.06
47	339	1.36	1.75	2.13
48	351	1.40	1.80	2.20
49	363	1.45	1.86	2.28
50	375	1.50	1.92	2.36
51	388	1.55	1.99	2.44
52	401	1.60	2.06	2.51

Temp.	Force of Vapour.	Evaporating Force in Grains per Minute. Leſſer Extreme.	Mean.	Greater Extreme.
53°	.415	1.66	2.13	2.61
54	.429	1.71	2.20	2.69
55	.443	1.77	2.28	2.78
56	.458	1.83	2.35	2.88
57	.474	1.90	2.43	2.98
58	.490	1.96	2.52	3.08
59	.507	2.03	2.61	3.19
60	.524	2.10	2.70	3.30
61	.542	2.17	2.79	3.41
62	.560	2.24	2.88	3.52
63	.578	2.31	2.97	3.63
64	.597	2.39	3.07	3.76
65	.616	2.46	3.16	3.87
66	.635	2.54	3.27	3.99
67	.655	2.62	3.37	4.12
68	.676	2.70	3.47	4.24
69	.698	2.79	3.59	4.38
70	.721	2.88	3.70	4.53
71	.745	2.98	3.83	4.68
72	.770	3.08	3.96	4.84
73	.796	3.18	4.09	5.00
74	.823	3.29	4.23	5.17
75	.851	3.40	4.37	5.34
76	.880	3.52	4.52	5.53
77	.910	3.65	4.68	5.72
78	.940	3.76	4.83	5.91
79	.971	3.83	4.99	6.10
80	.00	4.00	5.14	6.29
81	.04	4.16	5.35	6.54
82	.07	4.28	5.50	6.73
83	.10	4.40	5.66	6.91
84	.14	4.56	5.86	7.17
85	.17	4.68	6.07	7.40

In order to apply this table to practice, in finding the rate of evaporation at any time, ſuppoſe the dew-point found, as above directed, to be 45°, and the temperature of the air at the ſame time 70°. We find in this table, that the mean rate of evaporation at 45° is 1.62 grains in a minute; the rate at 70° being 3.72. Then 3.7 − 1.62 = 2.08 grains, the quantity evaporated in a minute, under ſuch circumſtances. If the example were to aſcertain the rate of any artificial evaporation, the temperature of the maſs expoſed muſt be taken, inſtead of the temperature of the air. It muſt alſo be obſerved, that if a briſk wind prevails, the grains evaporated muſt be taken from the column marked "greater extreme." If there be no wind, look at the "leſſer extreme" column; and in a moderate breeze, take the "mean" column. By this means we are enabled to aſcertain, at any time, not only the rate of evaporation, but the quantity of water contained in a cubic foot of ſpace.

From the decreaſe of temperature in the upper regions of the atmoſphere, and the greater decreaſe of the force of vapour at thoſe temperatures, the greateſt parts of the water which riſes from the earth will be precipitated at a very ſmall height.

If the temperature were taken by a thermometer, the degrees of which ſhould ſhew equal increments of heat, aqueous vapour at any temperature would become of half this denſity,

fity, by a decreafe of temperature equal to 25°. And fince, at the intervals of every fix miles above the furface of the earth, the preffure, and of courfe the force of vapour, is halved; the quantity of water in a cubic foot of fpace muft diminifh very faft with the height. At the temperature of 50°, when the atmofphere contains as much moifture as the temperature will admit, it contains only 3.5 grains in a cubic foot; and if the temperature upward were to vary no more than 25° for every fix miles, at 20 miles high there would be little more than one grain of water in a cubic foot of fpace. But the temperature is known to vary much more rapidly; and hence we fhould have much lefs water in the fame fpace, on account of the condenfation refulting from this greater decreafe. Still, however, fome portion of water muft exift in the very limits of our atmofphere, in a ftate of fteam or vapour of fome denfity; and this vapour is ftill within the limits of fact the 5th, before given, *viz.* If fuch vapour were compreffed till its denfity was equal to 253 grains in the cubic foot, its temperature would be 212°, whatever might be its temperature previous to its compreffion. The fame thing, as Mr. Dalton has very ingenioufly fuppofed, would be the cafe with the air itfelf; that is, if the rareft part of our atmofphere were condenfed to the denfity of that at the furface, its temperature would alfo become the fame. This change of temperature in elaftic fluids, by rarefaction or condenfation, is evidently owing to a change in their fpecific heat. We have lately heard of a fact, which has excited the curiofity of fome philofophers, and furprifed others, which is as follows. When fteam, of very confiderable denfity from preffure, is made to iffue from the mouth of a pipe, a perfon may place his finger clofe to the aperture, without feeling any unpleafant effect from the heat. The fenfible heat of this fteam, which would otherwife act, is abforbed by the fudden change of fpecific heat, by the expanfion of the fteam. This fact is very analogous to an experiment which has been long known. When the bulb of a thermometer is placed within the nozzel of a pair of bellows, and a blaft fent through them, the mercury rifes above the common temperature; but if the bulb be placed at a little diftance from the nozzel, the mercury falls below the common temperature. In the firft inftance, the air was compreffed, and the heat given out; in the fecond, heat was abforbed, and confequently the temperature lowered. The cold produced by the exhauftion of the receiver of the air-pump is to be explained in the fame way.

The change of temperature of the atmofphere is doubtlefs more regular at confiderable elevations, than near the furface: hence the air in which we live is frequently in a ftrong evaporating ftate, while condenfation is taking place in the fuperior regions. This gives rife to numerous clouds, which are nothing more than water in fmall globules, having loft their elaftic form by condenfation. The changes of temperature, which take place from the various currents arifing from the action of the fun upon the earth, materially and conftantly change thefe appearances; fometimes caufing the difappearance of opaque clouds, and at other times darkening the air by fudden condenfation. We can but, therefore, regard the water in the air as exifting in two ftates, namely, in the liquid and in the elaftic ftate, between which there can be no medium: for evaporation or condenfation muft be the refult of the flighteft change of temperature; at leaft we may conclude, that one of thefe proceffes will commence with the change, and will progreffively go on till as much water is either precipitated or taken up as the temperature will admit. Evaporation, as we have before obferved, can never be inftantaneous: even if the air did not mechanically refift it, the prefence of the vapour already formed would have that effect. Although there appears to be no medium between water and fteam, the actual precipitation of the water is progreffive, and is more or lefs rapid at different times. The clouds which appear to be fufpended in the atmofphere are conftituted by an affemblage of fmall globules of real water, which in vacuo would be precipitated with a rapidity agreeing with the laws of falling bodies; but in confequence of the refiftance of air, their defcent is retarded, being dependent upon the ratio between their furface and folidity.

There are good reafons for fuppofing that thefe globules are prevented from uniting by the prefence of electricity, as we know that they muft repel one another when they are fimilarly electrified. On the contrary, when particles are intermixed having contrary ftates of electricity, the condenfation will be much facilitated, as we perceive in rain immediately fucceeding thunder.

In all thofe fituations where fteam undergoes condenfation, we do not fee water immediately precipitated. The mifty appearance is caufed by fmall globules of real water falling towards the earth with a fmall but progreffive velocity. If the change of temperature caufing the condenfation be very flow, the globules are extremely fmall in the firft inftance, and are with more difficulty united. This is doubtlefs the cafe with all bodies which are perfect liquids. Globules of mercury are united with greater difficulty the fmaller they are. The ftate in which mercury exifts in lard in the form of unction, is in thefe minute globules produced by the mechanical action in mixing it. If boiling water be poured upon mercurial ointment, the fat is feparated and floats upon the water: this may be poured off, and the mercury will be left in minute globules, which are united with great difficulty. It occupies a much greater fpace than when united, having the appearance of froth. Such is the ftate of water forming the white fleecy clouds which we frequently obferve at a great height; the denfe dark-coloured clouds being compofed of larger globules which feldom remain long before they are more completely formed into drops of rain.

The clouds, therefore, are not to be confidered as abfolutely fufpended, but as water in globules of different magnitudes, falling with a velocity in the inverfe ratio of their magnitudes. There is nothing hypothetical in this idea, fince it is within the limits of calculation to afcertain the magnitude even of particles of lead falling through any affignable fpace in a given time. We cannot demonftrate the principle better than by folving the following problem.

What muft be the diameter of a globule of water, to be capable of falling one inch in a fecond, after it has acquired an uniform velocity.

Let c = the fpecific gravity of the air through which the fteam falls, water being 1.
p = 3.1416, &c.
g = the fpace a body falls in one fecond by gravity.
v = the velocity.
x = the diameter of the globule which is required.

Then, fince the particle will ceafe to be accelerated when the refiftance is equal to its weight, the velocity at that point will be v, which it will uniformly retain; all other things remaining equal. The fpace fallen through to give v, will be $\frac{v^2}{2g}$: this, multiplied by $\frac{px^2}{4}$, will give $\frac{pv^2x^2}{8g}$, the

 content

content of the cylinder of air; and $\frac{c p v^2 x^2}{8 g}$ = the weight of the cylinder. This would be equal to the refiftance, if the furface prefented to the refifting medium had been a plane perpendicular to the direction. The refiftance of fuch a furface to that of the fpherical one, is as 1 to 2. Hence the refiftance will be $\frac{c p v^2 x^2}{16 g}$.

The weight of a globule of water of the diameter a, will be $\frac{1}{6} p x^3 = \frac{c p v^2 x^2}{16 g} \therefore = \frac{3}{8} \frac{c p v^2}{g}$. Then, fince $v = 1$ inch, $g = 194$ inches $= .0018$, $p = 3.1416$, $\therefore x = \frac{3}{8} \times 1 \times \frac{1}{194}$ $.0018 \times 3.1416 =$ $\frac{3 \times .0018 \times 3.416}{8 \times 194} = .00001093$ of an inch, and in weight only .000000000000027 of a grain.

When we confider how inconceivably fmall the atoms of water muft be, it will be eafy to conceive globules of water much fmaller than the above calculation gives.

We are quite aware of the difficulties attendant on the beft theory of clouds and rain. If the view we have given is fupported by facts and obfervation, which at prefent appears to be the cafe, we may expect it to ftand on firmer grounds than has hitherto been the fate of numerous hypothefes, as it is free from any thing gratuitous or hypothetical.

Steam is at prefent applied to many economical purpofes, as well as in various manufactures, independent of its important office in the fteam engine.

In dyeing, bleaching, and many other fimilar departments, it is ufed to communicate heat to water, inftead of having feparate fire-places and boilers. The veffels to contain hot water, which were formerly feparate pans or boilers, are now fupplied from one principal clofe boiler, fimilar to thofe ufed for fteam-engines, by feparate fteam-pipes. When the economy of the fteam is confidered an object, the pipes for conveying the fteam fhould be cafed with wood, or otherwife covered with fome bad conductor of heat, which will not be attracted by the heat of 212°.

The boiler, which fupplies the fteam, fhould be placed lower than any refervoir of water which it has to heat, as in that cafe the water, which may fometimes condenfe in the pipes, may run back into the boiler. This affords a little economy, by faving the degrees of heat between the hot water and the cold, with which the boiler is fupplied. Another advantage is in the pipes not being liable to be choaked by the condenfing water not being allowed to get out of the way of the fteam. For heating water in brewhoufes, wafh houfes, dyeing-vats, &c. the fteam-pipe comes directly into the water, the fteam paffing into the fame making a loud noife, like the rapid cracking of a whip. For heating large baths and buildings, the fteam is condenfed in the pipes which pafs round the baths or around the rooms, and the water fhould in this cafe run back into the boiler. The pipes, or other metallic veffels in which the fteam is condenfed for the purpofe of warming rooms, fhould be coated with paint, the blacker the better. This is found to give out heat much more rapidly than the metallic furface, and in a ftill greater excefs above a polifhed metallic furface.

When fteam is employed for the purpofe of heating water, the fupply for a given quantity of water will be eafily calculated by the data already given.

Let L = the heat required to convert water into fteam at 900°.
W = the weight of the water to be heated by fteam.
T = its temperature.
t = the temperature to which it is required to be heated.
S = the weight of fteam required.
h = the temperature of the fteam.

Then $t = \frac{(L + h) S + W T}{S + W}$, and $S = \frac{t - T}{L + h - t} W$.

A fimple rule for finding the quantity of fteam required to raife a given weight to any given temperature arifes out of this formula. Multiply the water to be warmed by the difference of temperature between the cold water and that to which it is to raifed for a dividend. Then to the temperature of the fteam add 900, and from the fum take the required temperature of the water. This laft remainder being made a divifor to the above dividend, the quotient will be the quantity of fteam, in the fame terms as the water.

What quantity of fteam at 212° will raife 100 gallons of water at 60° up to 212°? $\frac{(212 - 60) \times 100}{900} = \frac{152}{9} =$ 17 gallons of water, formed into fteam. This quantity of fteam from a boiler containing about 27 cubic feet, with a fire applied to the beft advantage, will be furnifhed in 2 hours and 16 minutes, fuppofing no heat to be loft by the heated mafs being expofed. The coal confumed for this purpofe will be about 23 or 24lbs., depending on its quality.

The theorem above given will apply to any temperature above 212°, when the fteam is under greater preffure than 30 inches of mercury. It will alfo appear from the table of the force of vapour, that any degree of heat fhort of endangering the veffels, may be given by fteam under different degrees of preffure. Such means are at prefent employed for evaporating water from fugar, falt, and other fluids requiring a greater degree than 212. It will be equally obvious, that an uniform heat may be kept up below 212°, by adjufting the fteam-cock through which the medium to be heated is fupplied. In giving heats above 212°, the veffels fhould be completely fteam-tight, and very ftrong. The boiler fhould have a fafety-valve, which fhould always be kept clean and free to act.

Steam is employed to great advantage for culinary purpofes. It is made to communicate with veffels in the form of boilers, as a fubftitute for having fires under them, which is a great advantage, both in the economy of fuel, and in avoiding at the fame time the nuifance of afhes and fmoke.

The moft convenient application of fteam for culinary purpofes is, when it directly acts upon the fubftance to be heated. This has been generally effected by placing the fubftance, whether meat or vegetables, in a veffel without water, and allowing the fteam to enter and condenfe upon it. The moft convenient apparatus of this kind we have yet heard of, confifts of a caft-iron plate about 30 inches or three feet fquare, ftanding horizontally in a recefs in the wall, like a table. Round the edge of this plate is a groove, about half an inch wide and two inches deep. Into this groove fits an inverted tin-veffel, like a difh-cover. This is capable of being elevated and depreffed by a pulley and chain, having a coun-

terpoife, in order to expofe the table at any time. The fteam comes under the table and enters in the centre. The difhes to receive the heat are placed on any part within the groove, the fteam being common to all. The water refulting from the condenfation runs into the groove, and at a point fhort of the top runs off. The water which remains forms a complete water-lute, to prevent the efcape of fteam. The table being placed in a recefs, like a common ftone hearth, a fmall flue is placed over it to take away any fteam that may efcape when the cover is lifted up.

The great quantity of hot water required in a fcullery fhould be perpetually kept up by a fupply of fteam. For this purpofe a large cylindrical veffel of caft-iron fhould be elevated in a corner of the fcullery, in order that water may be drawn from it by a cock. This veffel fhould be connected from the bottom with a cold-water ciftern, the bottom of which is level with the top of the cylinder, by which the latter is kept conftantly full. The hot-water cylinder is clofed firmly at the top, and therefore, when the air is allowed to efcape, the water rifes to the top. If now a pipe be connected with the top, coming down to where it is to be drawn off, if any portion be drawn out here, as much will come in at the bottom of the cylinder from the refervoir above. So far we have defcribed this cylinder without its fteam-veffel. Within this cylinder, and about the middle, is a diftinct veffel, nearly of the width of the cylinder; but having a free fpace round the inner veffel about an inch wide. The depth of the inner veffel muft be about one-fixth that of the outer one. This inner veffel muft have no connection with the outer one, and muft be fo water-tight, that although it is furrounded with the water of the outer one, none fhould get in. The inner veffel is on one fide connected by a pipe with a fteam-boiler, having another pipe to allow the condenfed water to run off, which may be preferved as diftilled water, and is valuable for many purpofes. The heat arifing from the condenfation is communicated to the water in the outer veffel, the hotteft being at the top, where the mouth of the exit-pipe is placed. When, therefore, a portion of hot water is drawn from the cock, the pipe of which comes from the top of the veffel immediately under the cover, an equal quantity comes in at the bottom from the refervoir. This ufeful apparatus is the invention of an ingenious economift of Derby, and is at prefent in ufe in his kitchen.

When fteam is properly applied to the warming of baths, the economy is fo great, that if it were known, thefe exquifite luxuries would foon become more fafhionable. The fteam is condenfed in pipes about two or three inches in diameter, which are placed round the bottom of the bath. Thefe pipes are concealed in a recefs, which is afterwards covered by thin ftone plinths, perforated with holes to allow the water to circulate.

We fhall point out the economy of thefe baths, by giving fome facts of a bath in common ufe. Its fize is about 10 feet fquare, and its depth fuch as to contain about 520 cubic feet. The fteam at 212°, to firft raife it from 32° to 96°, will be found by the above theorem to be as much as will condenfe it into 33 cubic feet of water. This will be produced by 380lbs. of coal, including that required to raife the 33 cubic feet of water from 32° to 212°, which is always about $\frac{1}{6}$th of what will afterwards make it into fteam.

Suppofing the bath to have double doors, and a fmall fkylight inftead of common windows, it will be found, when the outer air is 45°, that the bath will not cool more than 4° in 24 hours. To reftore this every day, will require only $\frac{1}{16}$th of what was required to raife it from 32°. This will be about 23.5lbs. Suppofing the whole of the water to be changed by a regular inlet and outlet every 14 days, then the weekly fupply of coal for fuch a bath will be about 350lbs.

It is fuggefted by Dr. Darwin, that the art of boiling vegetables of all kinds in fteam inftead of water, might probably be managed to advantage, as a greater degree of heat might be thus given them, by contriving to increafe the heat of the fteam after it has left the water; and thus the vegetable mucilage in roots and feeds, as in potatoes and flour-puddings, as well as in their leaves, ftems, and flower-cups, might be rendered probably more nutritive, and perhaps more palatable; but that many of the leaves of vegetables, as the fummits of cabbage-fprouts, lofe their green colour by being boiled in fteam, and look like blanched vegetables. This etiolation of fome vegetables by fteam is probably owing to its diffolving their colouring matter, which may then become decompofed, and may render them lefs agreeable to thofe who choofe by the eye rather than the palate; which green colour is, however, heightened by boiling them in fome hard waters which contain diffolved lime or fea-falt, or by a flight admixture of common falt with foft water; an effect which is owing to the evaporation of a part of the marine acid, and to the remaining alkali which was the bafis of it, when applied to blueifh vegetables converting them into green, as in the common experiment of adding falt of tartar to fyrup of violets, or according to the cuftom of fome cooks who add a little pot-afh, or fixed vegetable alkali, to the water in which young peas are boiled, to make them green, and afterwards a very little fugar to fweeten them. And the fame effect of making vegetables green, when boiled in another kind of hard water, is probably produced by the lime which abounds in them, and which, like the vegetable alkali, when the aerial acid which was united with it evaporates, is faid to convert blueifh vegetable colours into green ones.

Steam has likewife lately been applied in gardening to the purpofe of forcing plants of different kinds in the winter feafon, in order to have their produce at an early period, as to the cucumber, and fome other vegetables of a fomewhat fimilar nature; but the exact manner of its application in this intention, fo far as we know, has not yet been communicated to the public; it is, however, by fome mode of flues, pipes, and other contrivances for conveying and containing it, fo as that its heat may be uninterruptedly, equally, and regularly afforded to the roots of the plants which it is defigned to pufh forward into the fruiting ftate. It is faid to have been ufed in fome inftances in different parts of Lancafhire with great fuccefs. But how far the expence and advantage of fuch a method may admit of and encourage its being introduced into general practice, have not, probably, yet been well or fully afcertained. If it fhould be found capable of perfectly fucceeding in this ufe, on more full and correct experience, it will, however, conftitute not only a neat and clean, but an elegant mode of forcing plants into fruit at early feafons.

It has been found that fubterranean fteams often affect the furface of the earth in a particular manner, and promote or retard vegetation more than almoft any thing elfe.

STEAM-*Engine*, or *Fire-Engine*, a machine very generally employed in this country as a firft mover of other engines and machines, its mechanical force or moving power being obtained from the expanfion or contraction of the fteam of boiling water. Until of late years this machine was called the fire-engine, becaufe it is in reality actuated by the fire which caufes the water to boil.

The

Steam Engine

The ſteam-engine is an invention highly creditable to human genius and induſtry, and is amongſt the moſt valuable applications of philoſophical principles to the arts of life. The invention of a ſhip, with all her acceſſories, and the degree of knowledge requiſite to conduct her through a diſtant voyage, are more ſtriking inſtances of the power of the mind of man, and of his enterpriſing diſpoſition; whether we conſider the number of ſciences which muſt be applied to practice in the conſtruction and management of a veſſel; or the advantages which mankind have derived from ſuch an invention, and the improvements which it has occaſioned in the ſtate of civilization, by uniting, in a great degree, all the inhabitants of the globe in one ſociety, who mutually ſupply each other's wants, and who all contribute their ſhare to the general ſtock of knowledge.

The ſteam-engine follows next to the ſhip in the ſcale of inventions; but in an Engliſh Cyclopædia it will take the lead, from the circumſtance of its being wholly invented, and brought into general uſe, by our own countrymen, within the ſpace of a ſingle century; and alſo as having been the principal means of effecting thoſe great improvements which have taken place in all our national manufactories within the laſt thirty years; and the increaſe of our commerce which has enſued.

The art of navigation is the reſult of the combined ingenuity and experience of all nations, from the earlieſt period of hiſtory to the preſent time; and the ſucceſſive and almoſt imperceptible improvements by which it arrived at its preſent ſtate of perfection, have many of them been the productions of accident, and for which we do not exactly know to whom we are indebted. But the ſteam-engine is the invention of a few individuals, all of them Engliſhmen, and brought into general uſe within a century. In the firſt beginning it was the reſult of reflection, and the production of a very ingenious mind; and every alteration in its conſtruction and principle was alſo the reſult of philoſophical enquiry.

General Principle of the Steam-Engine.—The force of the ſteam-engine is derived from the property of water to expand itſelf, in an amazing degree, when heated above the temperature at which it becomes changed into ſteam, or vapour, which being an exceedingly elaſtic fluid, it can be retained within the cloſe veſſel or boiler to which the heat is applied, even when it has an expanſive force ſufficient to make it fill, if left at liberty, 20 or 30 times the ſpace in which it is confined. In this ſtate the ſteam will exert a proportionate force or preſſure to burſt open the ſides of the veſſel in which it is retained; which force may be applied either to expel or raiſe up water from any veſſel into which the confined ſteam is admitted, or to give motion to a moveable piſton, which is ſo accurately fitted to the interior capacity of ſuch veſſel, as not to permit the eſcape of the ſteam between them.

Another ſource of the power of the ſteam-engine is the facility with which ſteam of a great expanſive force can be cooled by the application of cold water, and condenſed into the ſmall quantity of water from which it was originally produced. A partial vacuum can thus be made, in a very large veſſel, in an inſtant, and even in the ſame veſſel, which was, a moment before, filled with confined ſteam, exerting a great force to eſcape. The preſſure of the atmoſphere which tends to fill up this vacuum, can be made to produce the aſcent of water into the veſſel to any height leſs than twenty-four or twenty-five feet. Or the preſſure of the atmoſphere may be made to give motion to a piſton, by admitting the atmoſpheric air to preſs upon one ſide of the piſton, whilſt there is a vacuous ſpace formed by the condenſation of the ſteam which filled the cylinder on the other.

Notwithſtanding the great variety of different conſtructions of the ſteam-engine, they all derive their force from one of theſe two principles, or from the combination of the two: but before entering upon any deſcription of the manner in which theſe forces are applied, it is neceſſary to have clear ideas of the nature of ſteam, and of the law by which it expands by heat, in order to form a preciſe judgment of what paſſes in the interior part of a ſteam-engine when it is at work. In the common acceptation of the word ſteam, it is that hot white vapour which we ſee every day riſing in a cloud from a tea-kettle or boiling-pot; but this is not exactly the ſtate of the ſteam employed in an engine; it is there perfectly tranſparent, and is more or leſs hot than boiling water, according as it is retained under a leſſer or greater degree of compreſſure. The ordinary preſſure of the atmoſphere, bearing upon the ſurface of water, will retain it in a ſtate of fluidity, until it is heated to what is generally called the boiling point, and is marked 212° in Fahrenheit's thermometer. If the heat is increaſed above that degree, and if the water is unconfined, except by the preſſure of the atmoſphere, the water immediately aſſumes the aeriform ſtate, and flies off in elaſtic vapour, which we call ſteam; but if the ſame water is relieved from the preſſure of the atmoſphere by encloſing it in a cloſe veſſel, and exhauſting the air from it, a certain portion of ſteam or vapour will riſe from the ſame at any temperature, even when it is as low as freezing; and if this vapour is conveyed off from the veſſel as faſt as it riſes, the water, although cold, will boil, and ſuch vapour will riſe as faſt as the boiling kettle does in the open air. If the vapour is retained in the veſſel, it will only accumulate, until it has acquired a certain degree of elaſtic force to preſs upon the ſurface of the water, which will then ceaſe to yield any more vapour, until the heat is farther increaſed, or that the vapour is drawn off to relieve the water from the preſſure which confined and retained it in its fluid ſtate. On the other hand, water which is retained in a cloſe veſſel, under a greater degree of preſſure than that occaſioned by the preſſure of the atmoſphere, will not boil or riſe in vapour, until it becomes heated to a higher temperature than 212°. It is even probable, that water might be compreſſed to that degree, that it would not boil until heated red-hot; but this would require ſuch an enormous ſtrength in the veſſel which ſhould contain the ſteam, that it is far beyond the practicability of an experiment.

In this manner the reader is to bear in mind, that vapour or ſteam, when confined in cloſe veſſels, is always more or leſs elaſtic, in proportion to the degree of heat which is applied to it; or, in other words, that the temperature of the ſteam is an exact index of the elaſtic or expanſive force with which it preſſes upon the ſurface of the water, and againſt the interior ſurface of the veſſel which contains it.

The following tables ſhew the law by which the expanſive force increaſes with the increaſe of the temperature. They were made from the experiments of Mr. John Dalton, which he publiſhed at length in the "Memoirs of the Literary and Philoſophical Society of Mancheſter," and experiments have been alſo made in France by M. Betancourt, which do not differ from this table ſo much as to affect the reſults in any great degree, when applied to practice, in calculating the force of ſteam-engines. Theſe experiments were made by encloſing water in a cloſe veſſel, from which the air was carefully exhauſted, ſo as to make a vacuum. A thermometer was applied, ſo as to indicate

the temperature of the interior of the veſſel; alſo there was a communication made from the veſſel to the lower part of a ſiphon barometer tube, that is, an inverted glaſs ſiphon filled with mercury, from one leg of which the preſſure of the atmoſphere was excluded, and the other leg communicated with the interior of the veſſel. In this way, when there was a vacuum in the veſſel, the ſurface of the mercury in the two legs of the ſiphon would ſtand at the ſame level, becauſe it would not be preſſed upon at all on either ſide; but when any vapour was raiſed in the veſſel, it would preſs upon the interior ſurface thereof, and alſo upon the ſurface of the mercury in one of the legs of the inverted ſiphon; and as the ſurface of the mercury in the other leg would not be preſſed upon at all, the mercury would mount in one leg and deſcend in the other, and the difference of the level between the two being meaſured, would expreſs the elaſtic force of the vapour, which was found to increaſe with the increaſe of the heat, according to the ſecond column of the table. For the convenience of eſtimating the force of the vapour, we have added the third and fourth columns to Mr. Dalton's table. The third, to expreſs the preſſure by the altitude of a column of water, inſtead of mercury; and the fourth column to ſhew the preſſure upon each ſquare inch of the ſurface upon which the vapour acts, in pounds avoirdupois and decimals. The table alſo ſhews, in the three laſt columns, the difference of preſſure between the vapour and atmoſpheric air in three different terms, *viz.* in the column of mercury, column of water, and in pounds on the ſquare inch.

In the firſt table, which is for every 10° of temperature up to 212°, or the heat of boiling water when in the open air, the three laſt columns ſhew how high the preſſure of the atmoſpheric air, when the barometer is at 30 inches, will force up mercury or water in a tube, which at the upper end communicates with the veſſel containing the vapour, and the lower end is immerſed in the mercury or water. And in the ſecond table, which is for the degrees of heat above 212°, the ſame columns ſhew to what height the force of the vapour will cauſe mercury or water to mount up in a tube, which at the lower end communicates with the veſſel containing the ſteam, and the upper end is open to the atmoſpheric air.

Table of the expanſive Force of the Vapour of Water, or Steam, when encloſed in a cloſe Veſſel, and relieved from the Preſſure of the Atmoſphere; taken at every 10° of Temperature, from the Congelation of Mercury, or 40° below the Zero of Fahrenheit, up to 212°, or boiling.

Temperature in Degrees of Fahrenheit's Thermometer.	Preſſure of the Vapour, or the Force which it will exert to enter into a vacuous Space.					Preſſure of the Atmoſphere, or the Force which it will exert to enter into a Space filled with the Vapour. Barometer ſuppoſed to be at 30 inches.				
	Column of Mercury.	Column of Water.		Preſſure *per* ſquare Inch.		Column of Mercury.	Column of Water.		Preſſure *per* ſquare Inch.	
	Inches.	Ft.	In.	Lbs.	Oz.	Inches.	Ft.	In.	Lbs.	Oz.
− 40 below zero.	.01	0	.17	0	.1	29.987	33	10.63	14	10.5
− 30 below zero.	.02	0	.27	0	.15	29.98	33	10.53	14	10.45
− 20 below zero.	.03	0	.4	0	.23	29.97	33	10.4	14	10.37
− 10 below zero.	.043	0	.58	0	.33	29.957	33	10.22	14	10.27
0	.064	0	.87	0	.5	29.936	33	9.93	14	10.1
10	.09	0	1.22	0	.7	29.91	33	9.58	14	9.9
20	.129	0	1.75	0	1.	29.871	33	9.0	14	9.6
30	.186	0	2.5	0	1.44	29.814	33	8.3	14	9.16
32 (freezing.)	.2	0	2.7	0	1 56	29.8	33	8.1	14	8.04
40	.263	0	3.5	0	2.	29.737	33	7.3	14	8.6
50	.375	0	5.1	0	2.9	29.625	33	5.7	14	7.70
60	.524	0	7.1	0	4 1	29.476	33	3.7	14	6.5
70	.721	0	9.8	0	5 6	29.279	33	1.	14	5.
80	1.	1	1.56	0	7.83	29.	32	9.24	14	2.77
90	1.36	1	6.5	0	10.4	28.64	32	3.25	14	0.2
100	1.86	2	1.25	0	14.4	28.14	31	9.5	13	12.2
110	2.53	2	10.25	1	3.6	28.47	31	0.5	13	7.
120	3.33	3	9.	1	10.	27.67	30	1.	13	0.6
130	4.34	4	10.75	2	1.5	25.66	29	0.	12	9.1
140	5.74	6	6.	2	13.	24.26	27	4.	11	13.6
150	7.42	8	4.5	3	9.8	22.58	25	6.25	11	0.8
160	9.46	10	8.	4	9.9	20.54	23	2.	10	0.7
170	12.13	13	8.5	5	14.7	17.87	20	2.25	8	11.9
180	15.15	17	1.5	7	6.4	14.85	16	9.25	7	4.2
190	19.00	21	3.5	9	3.3	11.	12	7.25	5	7.3
200	23.64	26	8.5	11	8.9	6.36	7	2.25	3	1.7
210	28.84	32	7.	14	1.9	1.16	1	3.	0	8.7
212 (boiling.)	30.	33	10.75	14	10.6	the vapour and the atmoſphere equal.				

Table

Table of the expanſive Force of Steam, when encloſed in a cloſe Veſſel, taken at every 5° of Temperature, from 212° of Fahrenheit, or boiling, up to 325°.

Temperature in Degrees of Fahrenheit's Thermometer.	Preſſure of the Steam, or the Force which it will exert to enter into a vacuous Space.					Preſſure of the Steam againſt the Atmoſphere, when the Barometer is at 30 Inches, or the Force which it will exert to eſcape from the cloſe Veſſel into the open Air.				
	Column of Mercury.	Column of Water.		Preſſure *per* ſquare Inch.		Column of Mercury.	Column of Water.		Preſſure *per* ſquare Inch.	
	Inches.	Ft.	In.	Lbs.	Oz.	Inches.	Ft.	In.	Lbs.	Oz.
212 (boiling.)	30.	33	10.75	14	10.6	the ſteam equal to the atmoſphere.				
215	31.83	35	11	15	9	1.83	2	0	0	15
220	34.99	39	6	17	1	4.99	5	7	2	7
225	38.20	43	2	18	10	8.20	9	4	4	0
230	41.75	47	2	20	7	11.75	13	4	5	13
235	45.58	51	6	22	5	15.58	17	8	7	11
240	49.67	56	1	24	4	19.67	22	3	9	10
245	53.88	60	10	26	4	23.88	27	0	11	10
250	58.21	65	9	28	8	28.21	31	11	13	14
255	62.85	71	0	30	12	32.85	37	2	16	2
260	67.73	76	6	33	2	37.73	42	8	18	8
265	72.76	82	2	35	9	42.76	48	4	20	15
270	77.85	87	11	38	1	47.85	54	1	23	7
275	83.13	93	11	40	11	53.13	60	1	26	1
280	88.75	100	3	43	7	58.75	66	5	28	13
285	94.35	106	7	46	3	64.35	72	9	31	9
290	100.12	113	1	49	0	70.12	79	3	34	6
295	105.97	119	8	51	4	75.97	85	10	36	10
300	111.81	126	4	54	12	81.81	92	6	40	2
305	117.68	132	11	57	9	87.68	99	1	42	15
310	123.53	139	6	60	8	93.53	105	8	45	14
315	129.29	146	1	64	0	99.29	112	3	49	6
320	135.	152	6	66	1	105.00	116	5	51	7
325	140.70	158	11	68	14	110.70	125	1	54	4

Hiſtory of Invention of the Steam-Engine.—The great elaſtic force of ſteam has been long known in the inſtrument called the *aeolipile* (ſee that article); and its property of condenſation was alſo experienced in the uſe of the ſame inſtrument: the manner commonly practiſed for filling the ball with water being to plunge it into cold water, when heated and filled with ſteam; by which means the ſteam is condenſed, and forms a vacuum ſufficient to draw the water into the ball, although the orifice is ſo ſmall that water could not be introduced by any other means. At the ſame time, the true principles of its action were ſo little underſtood, that the ſteam which iſſued from it, when placed on the fire, was ſuppoſed to be air produced by the decompoſition of the water; and nearly all the old philoſophers, who have deſcribed this inſtrument, propoſed to employ it for blowing furnaces. The firſt idea of employing this force of ſteam to produce motion was by Brancas, a philoſopher of Rome, who contrived a great number of different kinds of mills to be worked by the ſteam coming from a large aeolipile, and blowing againſt the floats or vanes of a wheel. We are obliged to this author for a number of other ingenious inventions, which he dedicated to M. Canci, governor of Loretto, in 1628, and publiſhed his work (Le Machine) at Rome the year following. The repreſentation of his fire-machine is given in the twenty-fifth plate; but the force which he could have thus obtained from ſteam would have been found altogether inconſiderable, if he had ever put it in practice.

The firſt real ſteam-engine was invented by the marquis of Worceſter; but it was only for raiſing water, and that by the expanſive force of ſteam alone. The next engine was by captain Savery, and operated, both by the expanſive force and the preſſure of the atmoſphere, to fill up the vacuum which was produced by the condenſation of the ſame ſteam, after it had ceaſed to operate by its expanſion. Theſe actions were employed alternately to raiſe water. The third inventor, Newcomen, abandoned the force of expanſion, and only employed the condenſation of the ſteam to obtain a vacuum, and cauſe the preſſure of the atmoſphere to act, unbalanced upon a piſton, fitted into a cylinder; and as the force was thus exerted upon a moveable piſton, his machine is capable of being applied to give motion to pumps or other machines, whereas his predeceſſors were obliged to confine themſelves to the raiſing of water. Soon after this invention, engines were propoſed with piſtons to be actuated by the expanſive force of the ſteam only, without the vacuum. Laſtly, Mr. James Watt invented the engines now in general uſe, which are actuated both by the preſſure of ſteam, and the vacuum acting at the ſame time upon the oppoſite ſurface of the piſton.

We owe too much to theſe inventors, as well as many others, to paſs over their diſcoveries with ſuch ſlight notice; and ſhall, therefore, give a detailed hiſtory of the progreſs of this valuable invention, drawn from the beſt authorities we have been able to obtain.

The Marquis of Worceſter's Steam-Engine.—The earlieſt

description which we have of a machine for raising water by fire, employed in raising steam from boiling water, is from the marquis of Worcester, who, in the reign of king Charles II., and in the year 1663, published a small pamphlet, entitled "A Century of the Names and Scantlings of the Marquis of Worcester's Inventions," written in 1655.

This little work, it appears, was addressed to the king and parliament, and published with a view to obtain an encouragement from the public for the prosecution of 100 projects, which it details. No. 68. of this Century contains as follows:—"68. An admirable and most forcible way to drive up water by fire; not by drawing or sucking it upwards, for that must be as the philosopher calleth it *intrà sphæram activitatis*, which is but at such a distance. But this way hath no bounder, if the vessel be strong enough: for I have taken a piece of a whole cannon, whereof the end was burst, and filled it three-quarters full of water, stopping and screwing up the broken end, as also the touch-hole; and making a constant fire under it, within twenty-four hours it burst, and made a great crack; so that having a way to make my vessels, so that they are strengthened by the force within them, and the one to fill after the other, I have seen the water run like a constant fountain stream forty feet high: one vessel of water, rarefied by fire, driveth up forty of cold water. And a man that tends the work is but to turn two cocks, that one vessel of water being consumed, another begins to force and re-fill with cold water, and so successively; the fire being tended and kept constant, which the self-same person may likewise abundantly perform in the interim between the necessity of turning the said cocks."

This passage certainly contains a description of an engine for raising water by the repellent power of steam; and from his expression, of one vessel of water, converted into steam, forcing up forty vessels of cold water to the height of forty feet, it is very probable that he had actually tried the experiment by a working model.

The marquis concluded his Century of Inventions by a promise to leave to posterity a book, wherein under each head the means of putting his several inventions in execution were to be described, with the assistance of plates; but as this work never appeared, we can only judge of his abilities by this specimen. He appears to have been a person of much knowledge and ingenuity; but his obscure and enigmatical account of these inventions seems not so much intended to instruct the public as to raise wonder; and his encomiums on their utility and importance are, to a great degree, extravagant, resembling more the puff of an advertising tradesman, than the patriotic communications of a gentleman. The marquis of Worcester was indeed a projector, and very importunate and mysterious withal in his applications for public encouragement.

It does not appear that he met with any public encouragement to his propositions; and though, at first sight, it seems surprising that an invention, by which the steam of boiling water is stated to be capable of producing a power equal to that of gunpowder, should be neglected for almost forty years; yet if we consider that the greater part of this Century of Inventions consists of things highly in the style of legerdemain, and some of them absolutely impossible, and contrary to all established rules of science, we need not so much wonder at the neglect which the whole experienced. For example, the 99th number of the Century is as follows: "How to make one pound weight to raise an hundred as high as one pound falleth, and yet the hundred pounds descending doth what nothing less than one hundred pounds can effect."

It must be also further considered, that these projects were published at a time when true science was beginning to take place of empiricism.

The Century of Inventions appeared about three years after the establishment of the Royal Society, during the time of Mr. Boyle, Dr. Hooke, Dr. Wallis, sir Christopher Wren, sir Isaac Newton, and others equally skilled in calculations, as in the inventive parts of mechanics.

Under all these circumstances, it is not astonishing that the marquis's propositions in general should meet with a cool reception, or that this celebrated invention should be condemned to obscurity, amongst the other wonders with which it was accompanied.

We do not wish it to be understood, that all the marquis's propositions, except the fire-engine, are of the same nature as No. 99: on the contrary, several have been re-invented, and proved true, since the marquis's time; for example, short-hand telegraphs, floating baths, carriages from which the horses can be disengaged if unruly, combination locks, secret escutcheons for locks, candle-moulds, &c. It is also probable that others may be brought to perfection; yet the greater part is so much in the style of the wonderful, that it is to be wished that the marquis had published nothing but No. 63, which at once would have rendered his name immortal, and without any tarnish or alloy to the glory of so great an invention.

Captain Savery's Steam-Engine.—The next attempt upon record is that of captain Thomas Savery, a commissioner of the sick and wounded, who, in the year 1698, obtained a patent for a new invention for raising water, and occasioning motion to all sorts of mill-work, by the impellent force of fire. This patent bears date the 25th July, in the tenth year of the reign of William III., that is 1698. The patent states that the invention will be of great use for draining of mines, serving towns with water, and for working all sorts of mills.

In June 1699, he shewed a working model of his engine to the Royal Society, and in their Transactions for that year, *viz.* N° 253, vol. xxi. there is the following register.

"Mr. Savery, June 14th, 1699, entertained the Royal Society with shewing a small model of his engine for raising water by the help of fire, which he set to work before them: the experiment succeeded according to expectation, and to their satisfaction."

The above is accompanied with a copper-plate figure, with references by way of description, from whence it appears, that the engine then shewn by captain Savery was for raising water not only by the expansive force of steam, like the marquis of Worcester's, but also by the condensation of steam, the water being first raised by the pressure of the atmosphere to a given height from the well into the engine, and then forced out of the engine up the remaining height by the expansive force of steam, in the same manner as proposed by the marquis. This action was performed alternately in two receivers, so that while the vacuum formed in one was drawing up from the well, the pressure of the steam in the other was forcing up water into the reservoir; but both receivers being supplied by one suction-pipe and one forcing-pipe, the engine could be made to keep a continual stream, or so nearly so as to suffer very little interruption.

The inventor afterwards published an account of his engine in a small book, entitled "The Miner's Friend, or an Engine to raise Water by Fire described, and the Manner of fixing it in Mines, with an Account of the several Uses it is applicable unto, and an Answer to the Objections made against it," printed at London in 1702, by Thomas Savery, gentleman.

man. This little book was feparately addreffed to king William III., to whom the engine had been fhewn at Hampton Court, to the Royal Society, and alfo to the Mine Adventurers of England, who were invited to adopt the invention.

This engine difplays much ingenuity, and is almoft as perfect in its contrivance as the fame kind of engine has ever been made fince that time: we have on that account copied the principal figure, and captain Savery's own defcription, as given by Dr. Harris, in his Lexicon Technicum. See *Plate* I. *Steam-Engine, fig.* 1

Captain Savery's Defcription of his Fire-Engine.—"A denotes two furnaces, whofe fire-places are marked B 1 and B 2, and their common funnel or chimney C.

"In thefe two furnaces are placed two veffels of copper, which I call boilers, the one a larger, as L, the other a fmaller, as D.

"Thefe boilers have each a gauge-pipe, as G and N, of which G goes within eight inches of the bottom of the fmall boiler, but N reaches only half way down into the great boiler.

"By thefe pipes, before the engine can work, you muft fill the fmall boiler quite full, and the great boiler two-thirds full of water. Then light the fire under the large boiler at B 1, and make the water therein boil, by which means the fteam of it being quite confined muft needs be wonderfully compreffed, and therefore will, on the opening of a way for it to iffue out (which is done by pufhing the handle Z of the regulator from you), rufh with a great force through the fteam-pipe O 1, into the receiver P 1, driving all the air before it, and forcing it up into the force pipe through the clack R 1, as you will perceive by the noife and rattling of the clack; and when all the air is thus driven out, the receiver P 1 will be very much heated by the fteam. When you find it is thoroughly emptied, and is grown very hot, as you may both fee and feel, then pull the handle Z of the regulator towards you, by which means you will ftop the fteam-pipe O 1, fo that no more fteam can yet come into the receiver P 1, but you will open a way for it to pafs into O 2, and by that means fill the other receiver P 2 with the fteam, as the other was before.

"While this is doing, let fome cold water be poured on the firft-mentioned receiver P 1, by which means the fteam in it being cooled and condenfed, and contracted into a very little room, and confequently preffing but very little (if at all) on the valve or cock R 1, at the bottom of the receiver P 1, there is nothing there to counterbalance the preffure of the atmofphere on the furface of the water, in the lower part of the fucking-pipe T, wherefore it will be preffed up, and afcend into, and fill the receiver P 1, driving up before it, as it rifes, the clack or valve R 3, which afterwards falling down again and fhutting clofe, hinders the defcent of the water that way.

"Then (the receiver P 2 being in the mean time emptied of its air) pufh the handle of the regulator from you, and the force of the fteam coming from the boiler, will act upon the furface of the water contained in the receiver P 1, where it forces or preffes hard upon it, and ftill increafes its elafticity or fpring until it exceeds the weight of the column of water in the receiver and pipe S, which then it will neceffarily drive up through the paffage Q R, 1 Q Q, into the force-pipe S, and at laft difcharge it out at the top, as is reprefented in the figure.

"After the fame manner, though alternately, is the receiver P 2 filled and emptied of water, and by this means a regular ftream is kept continually running out at the top of the force-pipe S, and fo the water is raifed very eafily from the bottom of the mine, &c. to the place where it is defigned to be difcharged.

"Only I fhould add, that after the engine begins to work, and the water is rifen into and hath filled the force-pipe S, then it fills alfo the little ciftern X, and by that means feeds the pipe Y Y, which I call the condenfing pipe, and which can be turned fideways over either of the receivers, and will then be open: by this cold water is conveyed down from the force-pipe to fall upon the outfides of the receivers when thoroughly heated by the fteam, in order to condenfe the fteam within, and make them fuck (as it is ufually called) the water out of the well up into the receiver.

"Alfo a little above the ciftern goes the pipe E, to convey water from the force-pipe into the leffer boiler D, for the purpofe of replenifhing the great boiler L, when the water in it begins to be almoft confumed. Now when there is need of doing this, turn the cock E, fo that there can be no communication between the force-pipe S and the leffer boiler D; and putting in a little fire under the fmall boiler B 2, the water will there grow prefently hot; and when it boils, its own fteam, which hath no vent out, preffing on its furface, will force the water up the pipe H, through K, into the great boiler L, and fo long will it run till the furface of the water in the boiler D gets to be as low as the bottom of the pipe H, and then the fteam and water will run together, and by its noife, and rattling of the clack I, will give him that works the engine fufficient affurance that the fmall boiler hath emptied and difcharged itfelf into the greater one L, and carried in as much water as is then neceffary; after which, by turning the cock E again, you may let new cold water out of S into the leffer boiler D, as before, and thus there will be a conftant motion and a continual fupply of the engine, without fear of decay or diforder.

"Alfo, to know when the great boiler wants replenifhing or not, you need only turn the gauge-cock N, and if water come out there is no need to replenifh it, but if fteam only come, you may conclude there is want of water; and the like will the cock G do in reference to the leffer boiler D, fhewing when it is neceffary to fupply that with frefh water from S; fo that in working the engine there is very little fkill or labour required: it is only to be injured by either a ftupid or wilful neglect."

The engine above defcribed does not differ effentially from that reprefented in the print in the Philofophical Tranfactions, but it is more neatly put into form, and improved in fome of the minor particulars. For inftance, the original engine had only one boiler, and there was no means of fupplying it with water, to replace the wafte occafioned by the evaporation of the fteam, without ftopping the action of the engine whenever the boiler was emptied to fuch a degree, as to rifk the burning of the veffel. And after the boiler was replenifhed, the engine could not begin to work again, until that water which was introduced cold was made to boil.

The engine which we have juft defcribed from the Miner's Friend has a fubfidiary boiler, in which a quantity of water is reduced to a boiling heat in readinefs for fupplying the great boiler, and the power of the fteam raifed in the fubfidiary boiler is employed to force the water contained in it into the other, or great boiler, which actuates the engine: by this means the tranfpofition of the feeding water is not only inftantly performed, but being at a boiling heat, it is immediately ready to produce fteam for carrying on the work. There is alfo another grand improvement in the conftruction of this engine. His firft engine was worked by four feparate cocks, which the operator was obliged to turn

turn feparately at every change of ftroke; and if he turned them wrong, he was not only liable to damage the engine, but he prevented its effect, and loft a part of the operation; whereas in this fecond engine the communications are made by the double fliding-valve, or regulator, as it has fince been called. This is a brafs plate, fhaped like a fan, and moving on a centre withinfide the boiler, fo as to flide horizontally in contact with the under furface of the cover of the boiler, to which it is accurately fitted by grinding, and thus at pleafure opens or fhuts the orifices or entries to the fteam-pipes of the two receivers alternately. This regulator acts with lefs friction than that of a cock of equal bore; and by the motion of a fingle handle backwards, at once opens the proper fteam-pipe from one receiver, and clofes that which belongs to the other receiver.

The contrivance of the regulator has fince proved of more confequence, as having been univerfally adopted in the cylinder engines.

Captain Savery, in the Miner's Friend, above referred to, in addition to the defcription of his engine, enumerates the following ufes to which it may be applied, and which he defcribes rather fully, as follows; *viz.* 1ft, to raife water for turning all forts of mills; 2dly, fupplying palaces, noblemen's and gentlemen's houfes with water, and giving the means of extinguifhing fires therein, by the water fo raifed; 3dly, the fupplying cities and towns with water; 4thly, draining fens and marfhes; 5thly, for fhips; 6thly, for draining mines of water; and 7thly, for preventing damps in the faid mines.

Dr. Harris, in his account of the fire-engine, fpeaks of captain Savery as one that he was acquainted with, and as a perfon of great merit and ingenuity. He firft mentions another machine of Savery's, for rowing a fhip in a calm by paddle-wheels placed at the veffel's fide, of which the captain publifhed an account in 1698; and it is worthy of remark, that the fame kind of wheels, when actuated by improved fteam engines, is the only method, amongft an infinite number of others, which at prefent has been found to anfwer for rowing veffels. Dr. Harris, in proceeding to the fire engine, fays, "The other engine is for raifing water by the force of fire, in which he has fhewn as great ingenuity, depth of thought, and true mechanic fkill, as ever difcovered itfelf in any defign of this nature." Notwithftanding this, Dr. Defaguliers has endeavoured to take away all the merit of the invention of the fire-engine from captain Savery, as if he had merely copied it from the marquis of Worcefter.

The account given by Dr. Defaguliers has been fo frequently copied by different writers, that it is generally confidered as correct; and we therefore think it a piece of juftice to the memory of captain Savery, to fet his pretenfions in a clearer light than has been generally done. The doctor fays, "Captain Savery having read the marquis of Worcefter's book, was the firft who put in practice the raifing water by fire, which he propofed for the draining of mines. His engine is defcribed in Harris's Lexicon, (fee the word ENGINE,) which, being compared with the marquis of Worcefter's defcription, will eafily appear to have been taken from him, though captain Savery denied it; and the better to conceal the matter, bought up all the marquis of Worcefter's books that he could purchafe in Paternofter-Row, and elfewhere, and burned them in the prefence of the gentleman, his friend, who told me this. He faid that he found out the power of fteam by chance, and invented the following ftory to make people believe it; *viz.* that, having drank a flafk of Florence at a tavern, and thrown the empty flafk upon the fire, he called for a bafon of water to wafh his hands, and perceiving that the little wine left in the flafk had filled up the flafk with fteam, he took the flafk by the neck, and plunged the neck of it under the furface of the water in the bafon, and the water of the bafon was immediately driven up into the flafk by the preffure of the air. Now he never made fuch an experiment then nor defignedly afterwards, which I thus prove.—

"I made the experiment purpofely with about half a glafs of wine in a flafk, which I laid upon the fire till it boiled into fteam; then putting on a thick glove to prevent the neck of the flafk from burning me, I plunged the mouth of the flafk under the water that filled a bafon, but the preffure of the atmofphere was fo ftrong, that it beat the flafk out of my hand with violence, and threw it up to the ceiling. As this muft alfo have happened to captain Savery, if ever he had made the experiment, he would not have failed to have told fuch a remarkable incident, which would have embellifhed his ftory."

This conclufion of the doctor's is altogether unphilofophical, and does not at all invalidate captain Savery's account. We know that the marquis of Worcefter gave no hint concerning the contractibility or fudden condenfation of fteam, upon which all the merit of the modern engine depends. The marquis of Worcefter's engine was actuated wholly by the elaftic power of fteam, which he either found out, or proved by the burfting of a cannon, in part filled with water; but he gave not the leaft hint that fteam fo expanded is capable of being again fo far contracted in an inftant, as to leave the fpace it occupied in a veffel in a great meafure a vacuum. This grand difcovery was referved to captain Savery, and his account of its accidental origin is not at all improbable. The captain tells us in the Miner's Friend, that he did not bring his defign to bear, until after a great number of fatiguing inquiries: and he actually erected feveral machines before he obtained his patent in July 1698. Many objections were made againft the grant of that patent being paffed; but in the hearing of thefe objections, the difcovery of the marquis of Worcefter's prior claim was not mentioned: and, indeed, it is certain that the account given in the Century of Inventions could not inftruct a perfon who was not fufficiently acquainted with the properties of fteam to be able to invent the machine himfelf.

Defaguliers feems to have been too hafty in concluding that the captain had never made fuch an experiment as that of the wine-flafk, becaufe, in the fingle inftance in which he tried it himfelf, he found the effect of the condenfation took place in a much higher degree than reported by the captain. It is not difficult to conceive that a very fmall difference in the heat of the fteam which filled the flafk, and other circumftances, might create the whole of the difference in the refult. And, on the whole, there is no reafon to hefitate in believing that the captain actually took his hint of the condenfation of fteam from fuch an accident, and being of a very mechanical genius, he would naturally turn his thoughts towards the confideration of fuch a power; and the moft obvious application of it would be to a machine on a conftruction fimilar to that defcribed by the marquis. Or, if he really had been acquainted with, and confidered the marquis's engine, he would eafily fee that the new principle of condenfation might, with great advantage, be combined with the former, and thereby produce an effect more powerful than either of them could do alone. The only thing in the doctor's account which cannot now be difproved is, that captain Savery deftroyed the marquis of Worcefter's books. Even if this is true, it may be accounted for; the captain muft, firft or laft, have become acquainted with what had been before made public by the marquis of Wor-

cester; and after having in his books spoken of *his invention*, and his new power or cause of motion, and finding the marquis's inventions to be but little known, he might be tempted, in order to secure the whole credit and expected advantage to himself, to buy up the marquis's books and burn them. But the grounds for this assertion are very slight, and will never prevent the conclusion, that the great principle of obtaining force from the pressure of the atmosphere, by the condensation of the steam of boiling water, was a discovery for which we are indebted to captain Savery, who had also the merit of first reducing it to practice in a most complete manner, in combination with the prior discovery of the marquis.

M. Amontons' Fire-Wheel.—The French writers who have treated of the steam-engine, seldom fail to mention Papin and M. Amontons as the first inventors of the method of raising water by steam, and speak of Savery as a person who put their ideas in execution, and brought them to perfection: we think it right on this account to state what was done by M. Amontons and Papin, although the attempts of the latter to employ the force of steam are not entitled to any notice, either from their originality, or from their real merit. It is probable, that the news of the patent granted to Savery in 1698, for raising water, and occasioning motion to mill-work by the impelling force of fire, excited the attention of the French academicians, before the means by which it was to be accomplished were made public, so as to be known abroad, and that they were thus induced to attempt the same thing; for in June 1699, which is the same month that captain Savery shewed his machine at work before the Royal Society, M. Amontons delivered a memoir to the Royal Academy of Sciences at Paris, entitled "A commodious Way of substituting the Action of Fire instead of Men and Horses to move Machines."

This may be regarded as the first attempt to produce a circular motion by the means of fire, otherwise than by the aeolipile, or the fly of a smoke-jack: but as the motion of M. Amontons' wheel was to be produced by the alternate dilatation and contraction of air, and not of the steam of boiling water, it is nothing in common with Savery's machine, except that the first cause of motion is that of fire.

M. Amontons' fire-wheel, as he called it, consists of a number of close buckets, or chambers, placed in the circumference of a hollow wheel, and communicating with each other by valves opening in one direction; and a sufficient quantity of water is put into these buckets to fill about one half of the number: another circle of similar buckets, but of larger dimensions, are placed on the outside of the circle of the former buckets; these large buckets contain air, and each one has a pipe conducted from it to one of the water-buckets which are nearer to the centre: a part of the circumference of the wheel, which is about the level of the centre, is exposed to the fire of a furnace, so that each air-bucket that passes will be heated; and also the lower part of the wheel is immersed in a cistern of cold water, so as to cool the same bucket again. The action of the machine may easily be understood. The air contained in the large bucket which is opposite the fire becomes heated and expanded, and by the pipe of communication it enters into that water-bucket which is at the lower side of the wheel, and pressing upon the surface of the water therein, causes it to mount up through the other chambers, in the direction in which the valves open from one chamber to the next; the water, being thus accumulated in the chambers at one side of the wheel, will give it a preponderating power to turn round upon its axis. This motion brings another air-bucket opposite to the fire, and the air therein expands in its turn, and again elevates the water in the interior chambers as much as it had descended by the motion of the wheel; a continual succession is thus kept up, and the air-buckets which have passed the fire descend into the cold water, and the air is thereby cooled and reduced to its former bulk. By the communication with the water-buckets, the pressure of the expanded air is removed from within them, and puts them in a situation to repeat their action.

This machine is ingenious, and if a better application of fire, by rarefying water into steam, had not been discovered, it is possible that the invention of M. Amontons might have been further prosecuted. From his computations it would appear, that the machine he proposed would act with a considerable power; but as he exhibited no working model, or actual trial, it was never proved that the machine, if put into practice, would be capable of producing any thing near the effect promised by his calculations. Leupold, in his "Theatrum Hydraulicarum," 1724, proposed an improved form of this fire-wheel; and steam-engines have been since made with mercury, or fluid metal, contained within a hollow wheel, which is to be always kept on one side with the mercury by the force of the steam: they have not been found to equal other modes of applying the force of steam. Such of our readers as are curious to know more of the construction of M. Amontons' machine, can consult the original memoir; and they will also find a full account of it, with a figure, in Martin and Chambers's Abridgment of the Philosophical History and Memoirs of the Royal Academy of Sciences at Paris, vol. i.

Papin's Pretensions to the Invention of the Steam-Engine.—M. Papin, to whom the French attribute the invention of the steam-engine, was a doctor of physic, and professor of mathematics at Marpurg, in Germany, and in 1680 he was elected a fellow of the Royal Society of London. In the following year, and whilst in London, he invented and published a method of dissolving bones, and other animal solids, in water, by confining them in close vessels, which he called digesters, and which he made sufficiently strong to retain the steam and prevent all evaporation, so as to acquire a great degree of heat. About the same time Dr. Hooke, the most inquisitive experimental philosopher of that inquisitive age, observed that water could not be made to acquire above a certain temperature in the open air, and that as soon as it begins to boil, its temperature remains fixed, and an increase of heat only produces a more violent ebullition, and a more rapid waste. Papin's experiments with his digester rendered the elastic power of steam very familiar to him, and when he left England, and settled as professor of mathematics at Marpurg, he made many attempts to employ this force in mechanics, and even for raising water.

By his own account, it appears that he had made some experiments with this view in 1698, by order of Charles, landgrave of Hesse, but without effecting any thing. This is all the reason the French have to consider him as the first inventor of the steam-engine. Nine years after Savery's patent he published an account of his invention, in a tract, entitled "Ars nova ad aquam ignis adminiculo efficacissime elevandum"—"A New Method of raising Water by the Force of Fire," printed at Cassel, 1707. This machine, which is described in Belidor's "Architecture Hydraulique," vol. ii. does not essentially differ from that of the marquis of Worcester, but is far less perfect than Savery's: it works wholly by the repellent power of steam: the only advantage is, that the receiver being made cylindrical, the steam is separated from the cold water by a floating piston, and that the water is made to flow in some degree constantly, by being thrown into a large air-vessel. In this publication, Papin

admits that he had feen a draft of Savery's engine, but fays, that in the year 1698 he made a great number of experiments, by order of his ferene highnefs Charles, landgrave of Heffe, in order to raife water by the force of fire, which he communicated to feveral perfons, and particularly to M. Leibnitz, who anfwered, that the fame thought had occurred to himfelf. He alfo acknowledged that captain Savery was about that time working upon the fame fubject in England, and that Savery had firft publifhed the fruit of his refearches; that from 1698 the affair had lain dormant till the year 1705, when he received a letter from M. Leibnitz, then in London, which contained a draft of captain Savery's engine, and defired Papin's opinion upon it. On fhewing this draft to the landgrave, he ordered Papin to refume the work, and perfect the inventions which he had begun; and which Papin then publifhed, not with a view to make it fuppofed that captain Savery had taken the thoughts from him, but to fhew the world its obligation to the landgrave, in having *firft* formed a defign fo ufeful, and in having brought it to its prefent degree of perfection; and he labours much to fhew that his engine is preferable to that of captain Savery. Although we muft allow Dr. Papin to compliment his patron and himfelf upon the fuccefs they met with, after encountering many unforefeen difficulties and experiments, which fucceeded, as he tells us, *quite contrary* to their expectations, yet it cannot be allowed that Papin's experiments in 1698 were the firft, becaufe the marquis of Worcefter's publication was earlier by no lefs than thirty-five years; nor were they probable to have been fo early as Savery's beginning, fince we cannot fuppofe that he would be at the expence of a patent, without fome previous experiments to confirm his fpeculation, or that he could bring his engine to the degree of perfection in which he exhibited it to the Royal Society on the 14th of June, 1699, in lefs than a year, at a period when workmen were not ready or fkilful in the execution of fuch machines as they now are in this country.

We have copied the figure of Papin's engine from Belidor, that our readers may be able to compare it with captain Savery's, and judge of the authority upon which M. Boffut has faid in his Hydronamique, that the firft notion of the fteam-engine was certainly owing to Dr. Papin, who had not only invented the digefter, but had, in 1695, publifhed a little performance defcribing a machine for raifing water, in which the piftons are moved by the vapour of boiling water, alternately dilated and condenfed. Now the fact is, that Papin's publication on the fteam-engine was in 1707, in which he concedes the invention to Savery. He had occafionally before that publifhed feveral inventions in the Acta Eruditorum, in which cylinders and piftons were to be employed, but they were not intended to be worked by fteam, but by gunpowder and air, as we fhall fhew hereafter.

Defcription of Papin's Engine.—The intention of Papin's fteam-engine was to turn a water-wheel by a ftream of water iffuing with violence from an aperture or jet, the force of fteam being employed to throw the water into an air-veffel, from which it was to iffue by the re-action of the compreffed air. A fpheroidical veffel, A, (*fig.* 2.) of which the longeft axis is fuppofed to be 26 inches, and the leffer axis 20 inches, is placed in a furnace, fo that the fire can furround every part: this veffel or boiler, which is made of copper, fhould be two-thirds full of water, which is introduced by a tube B: a fiphon, C D, communicates from the boiler A to a cylinder G H, of 20 inches in diameter, and about the fame in height, which performs the office of the barrel of a pump, and in which plays a copper pifton, S T, made hollow within, that it may float upon the water: the bafe of this cylinder, which has no bottom, is joined to the extremity of a curved tube, I K O, which goes through the bottom of another cylinder, M N, of three feet in height, and 25 inches diameter, which is clofed at all parts, fo that the air cannot enter. A veffel Y, made like a funnel at the top, is adapted to the tube I K O, and ferves to introduce water into the body of the pump G H, beneath the pifton S T, which water can never rife above the pifton. A cock at E alternately opens and fhuts the communication through the fiphon C D, between the boiler A, and the body of the pump G H. When the communication is open, the fteam formed in A paffes into the upper part of the body of the pump, and preffes the pifton, which difplaces the water: this water cannot return into the veffel Y, becaufe a valve at R prevents it; it therefore rifes by the tube I K O, and difcharges itfelf into the cylinder M N, where it fills a part of the fpace occupied by the air contained in that cylinder, which, in confequence, acquires a great elafticity.

As foon as the pifton is arrived at the bottom of the body of the pump, the cock F is to be fhut, to ftop the paffage of the fteam, and another cock, P, at the top of the body of the pump, is to be opened, to permit the efcape of the fteam which has performed its office; then the weight of the water with which the veffel Y is always filled, opens the valve R, and introduces itfelf into the body of the pump G H, and makes the pifton S T to rife up again: the water contained in the tube K O is not to be confidered in this effect, becaufe a valve at K prevents it from defcending. When the water which is introduced into the body of the pump is come to an equilibrium with the water in the veffel Y, the cock P is to be fhut, and E is to be opened; the fteam comes again to prefs on the pifton, which it forces to defcend, and, as in the former inftance, expels the water through the tube K O into the cylinder M N, where it cannot introduce itfelf without furmounting the refiftance arifing from the elafticity of the air of which it comes to occupy the place.

The cylinder M N, which is three feet high, can contain about 86 cubic feet of water, or about 2.86 cubic feet at every foot in height; therefore, when it is filled to within two feet of the top, the air will be reduced to occupy only one-third of the fpace in which it was at firft fhut up, and it will have acquired an elafticity capable of making it fuftain a column of water of 64 feet, in addition to the 32 feet with which it is in equilibrium in its ordinary ftate of compreffion: under thefe circumftances, if the cock Q is opened, the water will fly out, at the firft inftant, with the fame velocity as if it was 64 feet high in the cylinder M N; but by degrees, as the water paffes out, it will be driven with lefs velocity, becaufe the air occupying a greater fpace, its elafticity diminifhes: but according to Papin's ftatement, there fhould always be at leaft a foot of water in the cylinder, and the air, in its fmalleft condenfation, fhould not occupy more than two-thirds of the fpace which it occupies in its natural ftate; and in that cafe it will have a fufficient preffure to fuftain a column of 16 feet of water.

M. Papin's machine is, on the whole, far inferior to the engine of captain Savery, as it wants the advantage of the grand principle of condenfation, and is only a return to the marquis of Worcefter's idea: it cannot therefore be called an improvement on Savery's, although it muft be allowed that the feparation of the hot fteam from the cold water by a diaphragm, pifton, or float, is a confiderable improvement on the marquis of Worcefter's, and would be alfo an advantageous addition to Savery's, if the condenfing water could be as well applied to run down the outfide of a cylindrical veffel as an oval one.

Long after Papin's publication, fome Englifh engineers made this addition to captain Savery's engine, and attempted

to introduce it in oppofition to the cylinder or atmofpheric engines, of which we fhall hereafter fpeak; but the confumption of fuel was too great to balance the advantage of fimplicity in the ftructure of the engine.

Captain Savery muft have been employed a confiderable time with his machine prior to the 14th of June 1699, and even previous to his patent, as may be inferred from his Miner's Friend, printed in the year 1702, where, in his addrefs to the Royal Society, he fays, that fince the time he exhibited his model to them, "I have met with great difficulties and expence to inftruct handicraft artificers to form my engines according to my defire; but my workmen, after much experience, are become fuch mafters of the thing, that they oblige themfelves to deliver what engines they make me exactly tight, and fit for fervice, and as fuch I dare warrant them to every body that has occafion for them."

In his addrefs to the gentlemen adventurers in the mines of England, he fays, that the frequent diforders and cumberfomenefs of water-engines then in ufe "encouraged me to invent engines to work by this new force; that though I was obliged to encounter the *oddeft* and almoft infuperable difficulties, I fpared neither *time*, *pains*, nor *money*, till I had abfolutely conquered them."

Application of Savery's Engine, and its Defects.—Refpecting the real ufe which was made of captain Savery's invention, it appears that a number of fmall engines were erected, under the authority of the patent, for the fupply of noblemen's and gentlemen's feats in different parts of England, and for fuch purpofes they fucceeded very well; but for the fupply of towns, and the drainage of mines, where great quantities of water, and great perpendicular preffures were required, they were not well adapted. With refpect to the raifing water for turning mills, an application which readily fuggefted itfelf to the ingenious inventor, we do not think it was ever attempted, for at that period there were fcarcely any mills which could have fupported the expence of the erection, and maintenance of fuch engines, even where coals were cheap.

For the drainage of fens they were not well adapted, becaufe the height to which water is moft generally required to be raifed in fuch cafes is fmall, and the quantity very great; on this account feveral engines would always be wanted for one drainage, and a great part of the power would be loft, becaufe the perpendicular height would be very much lefs than the height to which the atmofphere would raife the water. To fhips we may conjecture that they never were applied, and this reduces their ufe to a very fmall compafs.

The principal reafons why they could not be fo generally employed in mines as the captain was led to expect, and which he laboured to bring about, was, that the working part of the engine muft neceffarily be placed from 22 to 26 feet above the bottom of the mine; and if, by any accident, the water fhould happen to rife above that level, the engine would be drowned and irrecoverably loft, without fome other engines to recover it.

As the power of fuction in this engine cannot extend more than 26 feet, the reft of the perpendicular lift muft be obtained by the expanfive force of the fteam; and for every 33 or 34 feet of altitude of this column, a preffure equal to the atmofphere muft be exerted on the infide of the boiler and receivers, tending to burft them open.

It is not found practicable, in conftant work, to force the water by fteam of more than three atmofpheres' preffure, or about 67 feet above the engine; and this limits the whole power of an engine, on Savery's plan, to about 90 feet.

On this account it would require a feparate engine for every 14 fathoms of the depth of a mine, and they muft raife from one to another; but if any one engine is deranged, the reft muft ftop likewife.

Another difficulty was in the quantity of water which could be raifed with fafety: the fize of his largeft boiler did not exceed 30 inches diameter, and the capacity of the receiver could be but fmall; and, therefore, the generality of mines would require more than one engine at the fame level. The charge, trouble, and difficulty, attending fuch a number, would naturally prevent their introduction, even in cafes where they would really have been of great fervice. Add to this, the confumption of fuel in Savery's engines was enormous, compared with the modern engines; and they were always in danger of blowing up, particularly when they were employed to raife water to any confiderable height.

Suppofe, for inftance, the water is to be raifed 100 feet; 25 may be done by fuction, and the remaining 75 feet muft be lifted by the force of the fteam. To effect this, the preffure within the veffel muft be more than three atmofpheres; and it will be feen by our table, that every fquare inch of the interior furface of the boiler and receiver will be preffed with a force of more than 32 pounds, tending to burft them open. This moderate height will, therefore, require very ftrong veffels, and all the joints muft be made with the greateft care; for although it is true that the preffure is much lefs than is ufual in pumps, and other hydraulic machines, in which there is a greater column of water, yet there is much greater danger of the veffels being burft by fteam of fuch great elafticity, than by an equal preffure of a column of water; becaufe the force of the fteam is always liable to be fuddenly increafed to a very great extent, on any acceffion of the heat; and the heat alfo tends to weaken the veffels, particularly the boiler, which fooner or later muft be reduced in thicknefs at the bottom, and will then burft.

According to Mr. Dalton's experiments, from which we have formed our tables of the expanfive force of fteam, it muft be heated to a temperature of 287° of Fahrenheit's thermometer, before it can overcome a column of water of 75 feet in altitude; and as this fteam muft come immediately in contact with the furface of the cold water in the receiver, which is perhaps as low as 40°, the condenfation of the fteam is exceffive for fome time, and muft continue until the furface of the water acquires nearly the fame temperature as the fteam; which, however, it will foon do, becaufe the heat is tranfmitted downward very flowly in fluids. When the furface of the water is fufficiently heated, the fteam, which before was condenfed as faft as it came in contact with the water, will begin to prefs upon the water; and as the heat and elafticity increafe, it will lift the column. But when it has expelled any of the water from the receiver, a new fource of condenfation is produced, from the cold furface of that part of the receiver which was before filled with the cold water; and this condenfation will be even more rapid than the former, becaufe the veffel, being neceffarily made of metal, will tranfmit the heat more rapidly than the water did, and delay the procefs of forcing out the water until the interior furface of the receiver is made as hot as the fteam. Captain Savery feems to have been fully aware of this, as he fays in the "Miner's Friend," that you may fee on the outfide of the receiver how the water goes out, as well as if it was tranfparent; for as far as the fteam is contained within the veffel, fo far it is dry without, and fo hot as fcarcely to endure the leaft touch of the hand; but as far as the water is, the faid veffel will be cold and wet where any water has fallen on it, which cold and moifture vanifh

vanish as fast as the steam, in its descent, takes the place of the water. Also, he says, the force of the steam presses upon the surface of the water, which surface, being only heated by the steam, it does not condense.

Improvement upon Savery's Engine.—The rapid condensation which must take place, when steam of a great elastic force is brought into immediate contact with the water, is an insuperable bar to the raising of water to any considerable height, on Savery's plan. The most obvious improvement was to employ a cylindrical receiver, with a floating piston, in the manner of Papin's: but this was only a partial remedy, because the condensation from the sides of the vessel still took place; and it was not until the piston was made to fit exactly into the cylindrical receiver, and the water kept out of it altogether, that the steam-engine was rendered an efficient machine. But this change, which was invented by Newcomen, introduces much complexity into the work. It becomes necessary to have a separate receiver, with a piston, or, in other words, a pump, to raise the water, and also machinery to communicate the motion of the steam-piston to that of the pump. The simplicity of Savery's engine, and the certainty of its action, rendered it very desirable to obviate its defects so far that it could be employed for mines, even after the more perfect engines were introduced. To avoid returning to the description of Savery's engine, we shall give a brief account of these attempts, before proceeding to the other engines.

The first improvement of Savery's engine was to introduce a small jet of cold water into the inside of the receiver, to perform the condensation, instead of throwing cold water upon the outside of the receiver: by this means a more perfect condensation is obtained, and with a less waste of cold water than by the original plan. The water is conveyed by a small pipe, which branches out from the great forcing-pipe, and enters into the receiver, where it turns down, and terminates with a ball, perforated in all directions, like the spout of a watering-pot, so as to disperse the water in a shower within the receiver. A cock is placed to stop the communication at pleasure; and this cock is opened to admit the cold water, when the steam is to be condensed. But it must be observed, that water cannot enter through this cock into the receiver the first instant that it is opened, because the pressure of the water in the force-pipe must be less than that of the steam within the receiver, and, therefore, the injection will not commence until after the steam-cock is shut, and then the condensation, or loss of heat, which always takes place within the receiver from the coldness of the water, will very soon diminish the heat, and consequently the pressure of the steam so far, that it will no longer balance the pressure of the same column of water, which it had just before lifted into the force-pipe. This being the case, the injection-water begins to run, and falls in a shower through the steam contained in the receiver. The sudden effect of this shower to produce the condensation is really surprising. The injection, being a portion of the same water which has just before quitted the receiver, must have the same temperature as that which was then in contact with the steam; and the difference in the rapidity of the condensation arises only from the dispersion of the water into drops. When the cold water is contained in the lower part of the vessel, the surface only of the water is exposed to the steam, and soon becomes so heated that it will not condense with that great rapidity which it does at first. On the other hand, a quantity of water dispersed in drops will be completely exposed to the steam, and will take up therefrom, in an instant, as much heat as will reduce the temperature of the steam, and increase the heat of the injection-water, until they approach to an equality of temperature. This being the case, it will easily be seen that the degree of condensation which can be obtained within the receiver will be in a ratio to the coldness and quantity of the injection-water; but the quantity required for injection is far less than when applied on the outside of the receiver, because the receiver will not transmit the heat of the steam through it so quickly, but the water must run down the outside of the receiver, and descend into the well, without being much warmed, and without having extracted much heat from the steam within.

The next improvement in Savery's engine was the addition of the safety-valve to the boiler. This was invented by Papin for his digester, to permit the steam to escape from the boiler into the open air, when it arrives at such a degree of pressure as to endanger the rupture of the vessels. The safety-valve, which is shewn in the figure of Papin's engine, *fig.* 2, is nothing more than a valve opening outwards, and well fitted to close an aperture which is made in the top of the boiler, and is kept shut by a weight or a lever, which is loaded with a weight, capable of sliding upon the lever in the manner of a steelyard; so that the pressure of the weight upon the valve can be regulated at pleasure, according to the strength of steam which is required: but, in all cases, it must be loaded so as to permit the steam to lift it up and escape, when it arrives at a pressure which would endanger the boiler or receiver. With a view to strengthen the boiler, hoops and internal radiating bars were tried, according to the idea of the marquis of Worcester; but this was found of very little service, because, on account of the condensation of the steam, it is much better to divide the mine into engines of from 70 to 80 feet lift, according to captain Savery's first proposition, than to attempt using steam of that degree of elasticity, which will require any such precaution.

In the Philosophical Transactions, N° 461, there is an account of a new way of producing steam of a great pressure. The boiler consists of an inverted conical vessel of iron, to the base or upper part of which a close and strong copper-head or hemisphere is joined by rivets all round: the lower part, or cone, is set in a reverberatory-furnace, to receive a sufficient heat from the flame to make it red-hot. The water is introduced into this boiler in a number of small streams, or jets, which are injected into it by a pipe, which descends through the cover, or spherical top, of the boiler; and in the middle of the cone several spouts are fixed, radiating from it like the arms of a wheel: the pipe must be carried up above the boiler, so as to have a column of a sufficient height to overcome the pressure of the steam, and also enter into the boiler with a considerable force; and by the radiating spouts it is dispersed in a shower upon the interior surface of the iron cone, and is thus converted into steam, which flies up to the copper-head, and is carried off by a pipe to the engine. The inventor proposed to make the tube with the radiating spouts to revolve, for the purpose of distributing the water more completely; but he probably never tried the experiment, or he would have found that the boiler would have been soon destroyed by the rapid oxydation of the iron which must take place from throwing water upon it when red-hot; and copper would have melted.

In 1717, Dr. Desaguliers made an engine on Savery's plan in an improved form. He says, that in considering Savery's engine with Dr. Gravesande, they thought there was a great waste of steam, by its constantly acting upon the receivers without intermission, the steam becoming useless until it had heated the surface of the water in the receiver, and also to a certain depth below the surface: but

if it were ſo contrived, that after the ſteam had preſſed up one receiver full of water, inſtead of being thrown into another, it ſhould be confined in the boiler till the receiver was refilled by the atmoſphere, and thus turned upon the water, the ſteam would have acquired ſo much force from its confinement, that it would preſs ſuddenly upon the ſurface of the water, and diſcharge a conſiderable portion of it even before it had heated the ſurface. In purſuance of this idea, they had a model made which could either be uſed with one or two receivers, and found, on experiment, that one receiver could be diſcharged three times in the ſame time that two could be diſcharged once. They alſo learned that captain Savery had made an engine at Kenſington with only one receiver, which acted very well. Deſaguliers then made ſeveral engines with a ſpherical boiler, provided with a ſafety-valve, and a receiver of about one-fifth of the capacity of the boiler, and of a cylindrical figure, tall, and of ſmall diameter in proportion. The ſteam and the injection-water were alternately admitted into the receiver at top through a double-paſſaged cock, the handle of which being turned towards the boiler, admitted ſteam; or, being turned towards the force-pipe, admitted the jet of cold water; but only one of theſe paſſages could be open at the ſame time. The ſmall branch from the force pipe which conveyed the injection-water to the double-paſſaged cock, had another cock in it to adjuſt the aperture, and regulate the quantity of water which ſhould flow into the receiver. The ſuction-pipe and force-pipe were the ſame as Savery's; but the valves were conveniently ſituated, ſo as to be readily acceſſible when they required repairs. Dr. Deſaguliers tells us that he made ſeven of theſe engines: the firſt was for the czar Peter the Great, for his garden at St. Peterſburgh, where it was ſet up. The boiler of this engine was ſpherical (as they were all in his way where the ſteam was ſo much ſtronger than air), and held between five and ſix hogſheads; the receiver held one hogſhead, and was filled and emptied four times in a minute. The water was drawn up by ſuction, or the preſſure of the atmoſphere, twenty-nine feet high out of the well, and then preſſed up eleven feet higher. The pipes were all of copper, but ſoldered to the ſuction-piece with ſoft ſolder, which held very well for that height; but he did not venture either upon a greater quantity for that height, or a greater height for that quantity; for if the quantity was larger than above, the boiler muſt have been greater, and the ſteam of the ſame force would have had a greater ſurface to act upon, which might have burſt the boiler, or would have required it to be made much thicker.

Another engine of this ſort, which he put up for a friend in 1730, drew up the water twenty-nine feet from the well, and then it was forced up by the preſſure of the ſteam twenty four feet higher, into a ciſtern holding about thirty tons, placed at the top of a tower, in order to run down again through a pipe or conduit, and play ſeveral jets in the garden. But ſometimes, no jets being played, the water was diſcharged at the height of ſix or eight feet out of the force-pipes to fill the ponds and water-meadows in dry weather, which it did with a leſs ſtrength of ſtream than what drove the water into the tower; or if the ſame ſteam was kept up, it would make eight or nine ſtrokes in a minute, inſtead of about ſix, as when the water was driven up into the ciſtern. Upon the ſafety-valve there was a ſteelyard, the place of whoſe weight ſhewed the ſtrength of the ſteam, and how high it was capable of raiſing water; but when the weight was at the very end of the ſteelyard, the ſteam, being then very ſtrong, would lift it up and go out at the valve, rather than damage the boiler. Twenty-five years after this engine was made, a man, who was entirely ignorant of the nature of the engine, without any inſtructions, undertook to work it; and having hung the weight at the farther end of the ſteelyard, in order to collect more ſteam, to make his work the quicker, as alſo a very heavy plumber's iron upon the end of the ſteelyard, the ſteam not being able to lift the ſafety-valve, the ſteelyard, loaded with all this unuſual weight, burſt the boiler with a great exploſion, and killed the poor man who ſtood near with the pieces that flew aſunder.

Theſe accounts ſhew how high, and in what quantity, this kind of fire-engine can ſafely raiſe the water. About as much fire as a common large parlour-fire was ſufficient to work this engine, and raiſe fifteen tons *per* hour; ſo that if the ciſtern was kept full, the jets could be made to play to entertain friends at any time, and then a man being ſent to light the fire under the boiler, the engine would raiſe water to ſupply the jets before the ciſtern was empty.

M. De Moura, of Portugal, ſent an engine to the Royal Society upon the principle of Savery's, but provided with apparatus to make it ſelf-acting, and to open and ſhut the valves at the proper inſtant. The receiver, boiler, ſteam-pipe, and injection-cocks, are the ſame as we have before deſcribed, together with the ſuction and forcing-pipes, and their valves. What is peculiar to this engine is, a float within the receiver, compoſed of a light ball of copper, which is not looſe therein, but faſtened to the end of an arm or lever, which is made to riſe and fall by the float, while the other end of the arm is fixed to an axis, and conſequently, as the float moves up and down, the axis is turned round one way or the other. This axis is made conical, and paſſes through a conical ſocket, which is ſoldered to the ſide of the receiver, and upon that end of the axis which projects beyond the ſocket; and, therefore, at the outſide of the receiver is fitted a ſecond arm, which is alſo moved backwards and forwards by the axis, as the float riſes and falls. By theſe means, the riſing and falling of the ſurface of the water within the receiver communicates a correſpondent motion to the outſide, in order to actuate the reſt of the gear, which regulates the opening and ſhutting of the ſteam and injection-cocks. A ſmall ciſtern is ſoldered to the outſide receiver, and, being kept full of water, ſurrounds the joint, or conical ſocket, through which the axis of the float paſſes: this keeps the axis and ſocket air-tight. The ciſtern is conſtantly kept full of water by means of a ſmall leakage from the force-pipe, through a wooden peg, and the drops are conducted by a packthread down to the ciſtern. A ſmall weight is applied to the arm on the outſide of the receiver, to counterpoiſe the float within; alſo upon the ſame arm is a ſlider, which being ſet nearer to, or farther from the axis, will riſe or fall a greater or leſs ſpace, as may be required; when the float within riſes or falls, and the ſlider can be faſtened by a ſcrew at any part. A chain is attached to the ſlider, and gives motion by means of a ſhorter chain to a balance, or tumbler, which moves on an axis, and opens and ſhuts the cocks. The firſt-mentioned chain paſſes over two pullies, ſupported by two arms, that are faſtened to the ſide of the receiver, which give a chain a proper horizontal direction: in order to move the balance to the end of the chain, a weight is faſtened ſufficient to raiſe the balance to a perpendicular poſition, and alſo to overcome the friction of the float, and its axis with the pullies and chain.

The balance moves upon an axis, which is ſupported in pieces projecting from the receiver; and it has three arms, one of which applies with a roller to the handle of the ſteam-cock, a ſecond acts upon the lever of the injection-

cock, and a third ſhort arm has a piece of chain, to link it to the chain before-mentioned, at the part where the ſame extended horizontally between the two pullies. The arms, which act upon the cocks, are ſo placed, as to ſhut the ſteam-cock the moment before the injection is opened, and *vice verſâ*.

To put the engine in motion, preſs down the arm of the axis, which raiſes the float within the receiver, and the counter-weight of the chain will bring the balance over to the right ſide, and in its motion will open the ſteam-cock, and ſhut the injection-cock: alſo open a ſmall gauge-cock in the top of the receiver, that the air may be diſcharged by the entrance of the ſteam into the receiver. This being done, ſhut the air-cock, and let go the arm of the balance: the weight at the end of the chain will bring over the balance to the left, and in its motion will ſhut the ſteam-cock and open the injection-cock, to admit a ſmall jet of cold water into the receiver, which preſently condenſing the ſteam into water, in a great meaſure leaves a vacuum in the receiver. In this ſituation the preſſure of the atmoſphere will cauſe the water to mount through the ſuction-pipe into the receiver, where, as its ſurface riſes, it makes the float aſcend, and depreſſing the arm on the outſide of the receiver, draws the chain and raiſes the balance, till it has paſſed the perpendicular, when it will fall over ſuddenly by its own gravity: in falling, the roller of one of its arms takes hold of the handle of the ſteam-cock, and opens it, whilſt the other one ſhuts the injection-cock. This fall of the balance takes place when the receiver is almoſt filled with water, and the balance cannot return till the ſurface of the water therein ſubſides, and ſuffers the float to deſcend. This takes place as ſoon as the ſteam ceaſes to be condenſed by the cold receiver, and acquires ſufficient elaſtic force from its heat to fill the receiver and drive out the water from the forcing-pipe. When the ſurface of the water deſcends the float ſinks, and ſuffers the counter-weight to draw up the chain. By the ſhort chain it draws the balance beyond the perpendicular towards the left, when it falls of its own accord; and in falling, the one arm takes hold of the handle and ſhuts the ſteam-cock, whilſt the other opens the injection-cock, as before.

In the "Machines approuvées par l'Academie for 1744," is a deſcription of an engine by M. Genſanes, which very cloſely reſembles M. De Moura's, but is more completely deſcribed.

Mr. Blakey's Engine on Savery's Principle.—Long after ſteam-engines ſuperior to Savery's had become general, an ingenious engineer, Mr. Blakey, made many attempts to introduce Savery's engine in an improved form. He obtained a patent in 1766, from the ſpecification of which it appears, that his improvement was to employ oil floating upon the ſurface of the water in the receiver, to form a piſton or diſk between the hot ſteam and the cold water, to prevent the ſteam being condenſed as ſoon as it touches the ſurface of the water; or air was to be admitted into the receiver for the ſame purpoſe. In this caſe, two receivers were to be uſed, one in the ſame ſituation as Savery's, which was to receive the air; and the hot ſteam, when admitted into it, forced the air to deſcend by a pipe to the ſecond receiver, which was at the bottom of the well, and expel the water therefrom, and elevate it in the force-pipe. By this means he hoped to prevent the ſteam coming in contact with the water, and avoid the condenſation.

Mr. Blakey afterwards made ſome alteration in the form of his engine, which is deſcribed as follows by Mr. Ferguſon: (ſee *Plate* I. *fig.* 3.) E is the boiler, ſet in a furnace ſo as to be ſurrounded with flame: F is the gauge-cock, to aſcertain the depth of water in the boiler: D the ſteam-pipe, to which is ſoldered the cock and funnel C, for filling the boiler before the engine is ſet to work: I is an air-veſſel, and T T an injection-pipe, which paſſes through acroſs the top of the receiver, and has ſmall holes pierced in it for the cold water to drop through and fall in a ſhower in the air-veſſel I, in order to form a condenſation: the end of the injection-pipe is carried into the ſteam-pipe D, to admit a ſmall quantity of water to run down the pipe D, and ſupply the boiler: V is a receiver, communicating with the air-veſſel I by a pipe; in the upper part of it is a cullender S, with ſmall holes to diſperſe the injection-water, which falls from the air-veſſel I, equally through the receiver V: O is a valve to admit air, which comes through the cock P into the receiver; and H is an occaſional cock, to let out the air and ſteam when the engine is firſt ſet to work: Q is a pipe from the receiver V, to the box which contains the valves B and N at the bottom of the forcing-pipe A, which conveys the water up to the reſervoir: M is the ſuction-pipe, to draw the water from the well up to the receiver: G is the fire-place belonging to the furnace, in which the boiler is ſet, and beneath it is an aſh-hole. It is needleſs to ſay any thing of the ſcaffold or the well, they being always made according to the ſize of the machine, and in proportion to the place in which it is to be erected. All the veſſels and pipes of this engine are made of ſtrong copper.

In order to ſet this engine at work, the reſervoir and pipe A A muſt be filled with water, which will be retained in the clack B; then more water muſt be poured into the funnel C, which is on the ſteam-pipe D; from thence it falls into the boiler E, and riſes to the level of the cock F, which muſt be open; but as ſoon as the water runs from it, the funnel-cock C, as well as the gauge-cock F, muſt be ſhut, and the air-gauge cock H muſt be opened. The fire is then to be put into the furnace G, and as ſoon as the water is in ebullition in the boiler it creates ſteam, which finds its way through the pipe D, and forces the air out of the veſſel I into the lower receiver V; the air is alſo forced out at the cock H, the ſteam following it with great velocity. In a ſecond or two the cock H muſt be ſhut, and inſtantaneouſly the injection-cock L muſt be opened, which lets cold water run through the end of the pipe T T, into the ſteam-pipe D, to replace that which has been evaporated out of the boiler E; and it alſo ruſhes out on all ſides from the little holes which are in the ſides of the pipe T T, into the air-veſſel I, and falls on the cullender S: this cold water makes a ſudden condenſation in the veſſels I and V, and forms a vacuum, which cauſes the atmoſphere to preſs on the water in which the lower end of the pipe N is immerſed, and the water aſcends the ſaid pipe with great rapidity, and paſſes through the clack N, and through the pipe Q, into the receiver V, till it riſes up to O, where is a floating-ball faſtened to a handle or lever, which in riſing turns the key of the cock P, and opens it: there is a valve at that end of the cock which is withinſide of the receiver V, ſo that as ſoon as the cock is opened, the valve O is forced up by the air, which ruſhes through with great quickneſs and noiſe into the veſſel I; and when that veſſel is full of air, the vacuum is deſtroyed and no more noiſe is heard, which gives the notice to ſhut immediately the injection-cock L: that being done, the ſteam recovers its force, and makes its way through the ſteam-pipe D, into the air-veſſel I; and as the ſteam increaſes, being much lighter than air, it keeps uppermoſt, and forces the air on the water which is in the receiver V, which water is forced through the pipe Q, and lifting up the clack at B, goes up the pipe A, and empties itſelf into the reſervoir at top. When all the water is expelled out of the receiver V, the air follows, and aſcends with

with great velocity through the water which is in the pipe A: two or three seconds after the noise of this is heard, the injection-cock L must be opened to let in cold water, and cause the same effect as before. The noise of the air rushing in and out of the receiver gives proper notice when the manager of this hand-engine is to open and shut the injection-cock, which is the only thing required to work this machine, when once it has been put in action, in the manner that has been described above.

This engine was not found to answer any better than Savery's, because the air will not make that complete separation between the steam and the cold water which the inventor expected; and there is a great loss of power to compress the air sufficiently to make it lift the column of water; and in order to get rid of this air it must be forced up the pipe, which takes as much power of steam as would be required to force up as much water as the air occupied the place of when in its condensed state. Mr. Blakey's intention in the injection of a small quantity of water into the boiler at every stroke, was the same as Mr. Payne's red-hot boiler, of which we have before spoken, but he was in practice obliged to employ a steam-cock in the pipe D, otherwise the steam which the boiler produces whilst the injection-cock is open would have been all condensed and lost.

Savery's engine can be usefully employed for lifting water 30 or 35 feet, which can be done principally by the suction, and with a very slight pressure for the remainder; but it is the most advantageous way to raise no more than 24 feet, and perform the whole lift by the suction, and even to allow the water a sufficient descent to empty the receiver by its own gravity, without forcing it in the least by the steam. In this form of the engine, the steam need have no greater elastic force than the atmospheric air, or just as much as is sufficient to make it enter into the receiver, as the water runs out. The temperature of the steam, according to our table, will then be only a little above the boiling point, or above 215°, and consequently the loss by the condensation is not so serious; and as the steam is not pressed upon the water, it is not brought into such close contact with the cold water, as in the forcing engines. In this way, the injection must be forced in by a small force-pump.

Mr. Kier's Engine on Savery's Plan.—An engine upon this principle, with various judicious improvements, was erected some years ago by Mr. Peter Kier, at his manufactory of coach axletrees, near Pancras, where, without any material repair, it has almost constantly been worked since, to raise water and turn a water-wheel. The proprietor states it to answer his purpose very well, because it works without an attendant, and regulates its own motions; and, as might naturally be expected, the wear and tear are also inconsiderable.

Plate I. *Steam-Engine, fig.* 4. represents this engine, taken in a section through the centre. R represents an oval boiler, seven feet long, five feet wide, and five deep. Mr. Kier considers it as being of dimensions sufficient to work a larger engine; a circumstance which must, in a certain degree, increase the consumption of fuel. It feeds itself with water conveyed through an elevated pipe, at the end of which is a valve. This valve does not open until the fall of the water within the boiler has suffered a float to subside, which by its actual weight assists to draw the valve open; but the float, by its tendency upwards, as the water in the boiler rises, serves effectually to close it. The water in the boiler, therefore, remains constantly at or near the same level. The steam is conveyed by a pipe, T A V, to a box B, through which, by the opening and shutting of a valve, it can be conveyed to the working chamber E. The axis, C, serves as a key to open and shut the valve: N O is a cistern of water, from which the engine draws its water through a vertical pipe, in which the valve Q is placed, to prevent the return of the water; G G is another cistern, into which the water is delivered through the pipe F, which is provided with a valve H, opening outwards; I M represents an overshot water-wheel, 18 feet in diameter, moving on the axis K L, and communicating its motion to the lathes, and other machines used in the manufactory. The water in both the cisterns becomes warmer than the hand, after working a short time; for which reason, the injection-water is forced up by a small pump from a well, supplied from the small stream on which these works are established. A leaden pipe passes from this forcing-pump to the upper or conical part of the chamber E, for the purpose of injecting cold water at the proper time. Neither of these could be represented with convenience in the present section.

The manner in which the steam and cold water are alternately admitted into the chamber E, remains to be explained. Upon the extremity, K, of the axis of the overshot water-wheel there is fixed a solid wooden wheel, about four feet in diameter: it is also represented in *fig.* 5, as seen in the front; *a*, *b*, *c*, *d*, are four cleats, all or any number of which may be fixed on the wheel at a time. Each cleat has its correspondent block, *e*, *f*, *g*, *h*, on the opposite surface of the wheel. The use of these is to work the engine. Suppose the wheel I M K, with all the revolving apparatus, be turned round by hand, one of the cleats meets in its rotation with a lever, which opens the steam-valve by a bar of communication reaching to the handle of the axis C, *fig.* 2. The steam consequently passes into the chamber E, and the steam-valve shuts again, as soon as the cleat has passed. Speedily after this, the correspondent block on the other side of the wheel meets another lever, which is similarly attached to the handle of the forcing-pump, and, therefore, throws a jet of cold water into the chamber, and condenses the steam. The pressure of the atmosphere then forces the water from the cistern N O, through the valve Q, towards the chamber E. When the engine has been long out of work, two or three strokes may be necessary to raise the water to the top of the chamber E. As soon as this is the case, the re-entrance of the steam suffers the whole body of water, above the valve H, to flow out of the chamber E, by its gravity.

The water which is raised is suffered to flow upon the overshot water-wheel, I M, through a sluice; and by that means keeps the work in motion, and replenishes the lower cistern. There is no reservoir for the injection-water, but the requisite quantity is driven up at each stroke.

Hence we see, that in effect this engine is the same as Savery's original engine, except that it is not applied for the immediate purpose of raising water, but gives motion to other apparatus; and it does not force the water by the steam at all. The water merely falls out of the chamber, and consequently never requires steam much stronger than the atmosphere. From the effect of this engine, under circumstances of such advantage, it may fairly be concluded, that the action of steam against water in forcing can never be beneficial, except at places where fuel can be had extremely cheap. It was found, at the first erection of this engine, that the consumption of steam, by contact with the water, was so great, that it could not be worked with advantage. This defect was remedied in the present engine, as well as in another which was at Norwich, by fixing a small air-valve in the steam-box, which is struck open by the machinery for an instant, immediately before the ad-

 mission

miſſion of ſteam. It may be preſumed, that, according to Mr. Blakey's idea, the air occupied a ſpace above the water, and prevented their coming together. Mr. Kier, however, is diſpoſed to think that the effect does not take place in this manner, but by ſome mixture and dilatation of the two fluids; becauſe he imagines the miſchief from the wet ſurface of the cylinder would remain the ſame, when the water deſcends. To get rid of this air, the ſteam in the boiler muſt be made ſo much ſtronger than the atmoſphere, as to ruſh into the receiver with ſufficient force to drive out the air through the ſame valve at which it entered, and which opens outwards for that purpoſe; but will ſhut, to prevent the air entering when the vacuum is made, except for an inſtant before the ſteam is admitted, when it is opened by the machinery. The motion of the overſhot water-wheel is regulated by an apparatus called a governor, invented by Mr. Watt, and which will be deſcribed in our account of his engine. It is a perpendicular axis, which revolves by communication with the engine, and carries round two pendulous balls; which pendulums move on a joint, fixed to the vertical axis. When the rotation is very quick, the balls fly out, and are applied to draw down a lever, which is connected with the ſluice of the upper ciſtern: the ſluice, therefore, is made to fall or riſe, according as the velocity of the engine is greater or leſs. By this diſpoſition, when the wheel moves very ſpeedily from lightneſs of work, or any other cauſe, the quantity of water thrown down from the upper ciſtern is immediately diminiſhed; and, on the contrary, the quantity of water is rendered greater, when the ſlowneſs of the movement ſhews that more is wanted.

The engine here deſcribed has been at work many years, and from the ſimplicity of its conſtruction has yet exhibited no proofs of wear.

Mr. Kier thinks it a profitable engine to himſelf, and that it would be ſerviceable for raiſing water where coals are cheap. It conſumes ſix buſhels of good coals in twelve hours' work, when in its beſt ſtate, or ſeven buſhels when at the worſt. Under theſe circumſtances it gives ten ſtrokes *per* minute, each throwing out ſeven cubic feet of water at an aperture of 20 feet above the water beneath. This quantity, namely, 70 cubic feet *per* minute, will weigh 4375lbs. raiſed 20 feet high, which being doubled, to reduce it to Deſaguliers' ſtandard height of 10 feet, will amount to 8750lbs. raiſed 10 feet high; and this divided by 550, the number of pounds in a hogſhead, will give a quotient of 16 hogſheads raiſed 10 feet, repreſenting the force of ſo many men, according to the eſtimate of that author, who reckons five men equivalent to one horſe. The reſult is not quite half what is performed, with an equal quantity of coals, by the improved engines, with a piſton of ſuch ſize as to be equal to 20 or 25 horſes. Philoſ. Journ. vol. i.

Several other engines have been erected upon this plan; and where the water which is raiſed is to be immediately boiled, they are very capital machines, becauſe all the loſs of heat is thrown into the water and warms it before entering the boiler, ſo as to economize the whole: for inſtance, for the purpoſe of raiſing water into the boilers for a ſalt-work or for a brewery, they are very applicable.

We have no accounts of the quantity of water which could be raiſed by Savery's original engine with a given quantity of fuel; but he tells us in the Miner's Friend, that to lift a three-inch bore of water 60 feet high, would only require a fire-place for the furnace of 20 inches deep, and 14 or 15 wide; the expence of fuel for which, he ſays, would be inconſiderable, when compared with the advantages to be derived from the uſe of the engine.

It has been propoſed to conſtruct a ſucceſſion of engines upon Savery's plan in a mine, to raiſe water by ſuction from one to another, and to have all of them worked by one common ſteam-boiler. For this purpoſe, the depth of the pit is divided into lifts of about 15 feet, and at each lift is a ciſtern, to receive the water raiſed by the different engines. Each engine conſiſts of a vertical ſuction-pipe, with the lower end immerſed in the water of the ciſtern of the engine below it, and a receiver at the upper end, which communicates with the ſuction-pipe through a valve, to prevent the deſcent of the water from the receiver through the ſuction-pipe. There is alſo a ſmall ſpout or pipe leading from the ſide of each receiver into each ciſtern, which is to receive the water after it is raiſed into the receiver; and the ends of theſe ſpouts are covered with valves, to prevent the water running back into the receivers from the ciſterns. All theſe receivers communicate with a common air-pipe, which leads up to the top cloſe receiver, or air-veſſel, ſituated at the top of the pit, which veſſel is of at leaſt double the capacity of all the receivers and the common pipe together. Immediately above the air veſſel is the ſteam-receiver, of equal capacity, and communicating with the air-veſſel by a pipe, which deſcends through the top of the ſame, and reaches nearly to the bottom of the air-veſſel, ſo that if there is any water in this veſſel, the end of the communicating pipe will be immerſed therein.

Suppoſe the ciſterns at the different ſtages, and alſo the lower or air-veſſel, nearly filled with water, and the air-pipe and the ſmall receivers filled with air, the action of the machine will be as follows: the ſteam is admitted from the boiler into the upper receiver, and expels the air therefrom through a proper cock or valve: when thoroughly filled with heated ſteam, the communication with the boiler is ſhut, and an injection of cold water thrown into the receiver; this condenſes the ſteam, and forms a vacuum in the upper receiver: this being the caſe, the air contained in the air-pipe and receiver, by its elaſtic preſſure upon the ſurface of the water contained in the great air-veſſel, cauſes the water to mount through the pipe of communication into the upper or ſteam-receiver. This cauſes the air in the pipes and receivers to occupy a greater ſpace than it did before, and being thus rarefied, it no longer balances the preſſure of the atmoſphere upon the ſurface of the water contained in each ciſtern; it therefore forces the water up the reſpective ſuction-pipes into the ſmall receivers, and will fill each of them one half with water, and then the air contained in the remaining half of each receiver, and in the great air-veſſel above, comes to its equilibrium. The ſteam is now admitted a ſecond time into the ſteam-receiver, and preſſing upon the ſurface of the water therein, allows it to deſcend by its gravity into the air-veſſel beneath, from which it expels the air, and by the communication of the air-pipe it enters into the upper part of each of the ſmall receivers down in the pit, and bearing upon the ſurface of the water in each, ſuffers it to flow out by its own weight through the ſpouts into their reſpective ciſterns. When they have thus diſcharged the water which they had before drawn up, the ſteam in the upper receiver is again condenſed, and this rarefies the air in the air-veſſel and ſeveral receivers, and draws up more water from each ciſtern; and thus the action of the machine continues as long as the boiler affords ſteam. In this plan, the water in the upper receiver is never changed; but the ſame water is conſtantly ſubjected to the action of the ſteam, and will thereby become heated ſo as to avoid the loſs of ſteam by the condenſation. But this at the ſame time introduces another difficulty, which the inventor had not foreſeen, *viz.* that the heat of the water will prevent a ſufficient condenſation

of the steam to obtain a vacuum: for instance, it is not necessary for an engine of this kind to have steam in the boiler of much greater pressure than the atmosphere: suppose it is equal to raising water two feet, by our second table this will be at a temperature of 215°. Now, according to our first table, in order to obtain such a degree of rarefaction of pressure within the receiver as to lift a column of 30 feet of water, the temperature must be cooled down to 120°; therefore, at every stroke of the engine a change of temperature must be made equal to 95°, *viz.* between 120° and 215°. On this account, such an engine would require a great quantity of condensing water, and it is probable that it would be better to make the water, which the engine raises, pass through the receiver, on Savery's plan, or at least such a portion of it, as will keep the temperature of the water in the receiver sufficiently low to obtain the condensation which we have above mentioned.

In employing air in this manner to transmit the force of the steam into other vessels, there is always the loss from the elasticity or compressibility of the air, which, in the case above stated, will be equal to one-half; because, when a sufficient rarefaction is made within the steam-receiver to cause the atmosphere to press upon it equal to 13lbs. upon the square inch, or to suck up water 30 feet, the air contained in the air-vessel and pipes will expand itself so as to balance one-half of that pressure; and, therefore, the degree of rarefaction within the small receivers will be only sufficient to raise the water 15 feet instead of 30. On the other hand, when the steam is admitted into the receiver, it must be in sufficient quantity to restore the air to its original density, before it will balance the pressure of the atmosphere, and allow the water to flow out of the receivers into their cisterns.

Fig. 5. represents a similar contrivance to the above, but it is for forcing. It was suggested by Mr. Kier, in 1783. A is a boiler, and B a steam-vessel: this last communicates with the vessels M, L, K, T, each of which, except the lower one, consists of two vessels; first, an external cistern, open at the top; and secondly, an interior receiver, immersed in the water of the cistern, and closed on all sides, except where it communicates with B, by the branches of the receiver, the pipe F G H descending from B, and where the pipes P, O, N, I, enter the upper part of each, and descend withinside nearly to the bottom, and also where there is a valve at the bottom opening upwards. If steam be let pass from A to B, the air will be driven from B through the pipes F, and press upon the surface of the water in the lower receiver T, and drive the same up the pipes into the vessel or cistern K, but not into the receiver K, because the pressure of the air within that receiver keeps the valve in the bottom of the receiver shut. The next step of the operation consists in closing the cock C, and opening D, out of which a portion of steam will be driven, by the re-action of the water forcing itself through the valve in the bottom of the receiver T, from its natural tendency to rise to the same level as the surface of the water in the pit or well; and on the same account the water will enter into the receiver, K, from the cistern in which it is immersed. The cock D is then to be closed, and C opened; in consequence of which, the contents of the receiver, T, will be forced up to the cistern, K, by the steam, as before, and the receiver, K, will discharge its contents through the pipe, N, into the cistern L.

The steam being again shut off at C, and the cock D being opened, as before, the receivers, T, K, and L, will fill as before, by the water from the exterior cistern entering through the valves in their bottoms, and a larger portion of steam will issue from D. A third repetition of the process will drive the contents of these three receivers a step higher; and a fourth repetition will cause the contents of the upper receiver, M, to flow out at P; after which, every alternation of the work with the cocks C, D, will throw out the same quantity from P.

The vessel B must necessarily contain a quantity of air capable of occupying the whole interior space contained in the closed receiver, with an allowance for the loss of bulk in condensation, under the pressure of a column of water equal to one of the lifts; and the quantity of steam to be discharged at each stroke, must occupy a space equal to that of all the water moved at each stroke; and must, in all cases, be considerably stronger than two atmospheres, in proportion to the heights of the lifts.

Other Proposals for the Improvement of Savery's Engine.— In the Memoirs of the Philosophical Society of Lausanne, M. Francois has described a steam-engine on Savery's plan, which he proposes to be used for draining fens or marshes, and has added machinery to open and shut the cocks; it has otherwise nothing remarkable. See Repertory of Arts, first series, vol. iv.

In the American Philosophical Transactions there is a description of a steam-engine, on Savery's principle, by Mr. Nancarrow, which is applied to raise water for turning a water-wheel. In this engine, the receiver, into which the steam is admitted, is a tall cylindrical pipe, with only a slight enlargement at the top to form the receiver; and the water is only raised by the pressure of the atmosphere: and to prevent the water being changed and continuing cold, so as to condense the steam, it is not suffered to run off immediately from the receiver, as in Mr. Kier's engine, but nearly at the bottom of the tall cylindrical pipe it is joined to a box, as shewn by the dotted lines in the figure of his engine, and from this box a second vertical pipe, or force-pipe, ascends to the reservoir which contains the water: the valve to prevent the return of the water is placed at the lower end of this second pipe.

By this means, the portion of water which comes in contact with the steam rises and falls in the receiver, and alternately draws and forces other water through the box below, from the suction-pipe, and into the force-pipe and reservoir. But this water, when it becomes heated, acts like a floating piston on the surface of the cold water to prevent the contact of the steam. Mr. Nancarrow proposed to employ a separate condenser and air-pump to produce the vacuum, instead of making an injection into the receiver; but this would be attended with no advantage; and we have before stated the objections to the water growing heated any more than superficially.

At the same time we think that a very good and simple engine might be made, if this form of the apparatus, in which the water shall never be changed, was applied to forcing by the pressure of the steam only, on the marquis of Worcester's plan, and not to attempt condensation, which it is impossible to effect perfectly, when the water has become very hot; but instead thereof, when the steam has exerted its force, to open a cock, and let off the steam into the open air. An engine of this kind, which only requires the additional receiver, is described in Leupold's Theatrum Machinarum Hydraulicarum, vol. ii. 1724.

The last improvement which we have noticed in Savery's engine, is by Mr. James Boaz, of Glasgow, who took out a patent in 1805, for seven different forms of the engine. In all these the receiver is made cylindrical, and a piston is applied to float upon the surface of the water, upon Papin's plan; and in the same manner as Nancarrow's engine

he propofes to employ fuch an arrangement of the force-pipes, and of a fecond fmall receiver, that the water which comes in contact with the fteam fhall not be changed, but fhall always remain the fame; a method which precludes the ufe of the vacuum by condenfation. The fpecification of this patent is publifhed in the Repertory of Arts, vol. viii.

Newcomen's, or the Atmofpheric Steam-Engine.—This engine is named after its inventor, Mr. Thomas Newcomen, an ironmonger of Dartmouth, in Devonfhire. He appears to have been a perfon of ingenuity, and of fome reading, and was acquainted with the famous philofopher Dr. Hooke. Newcomen was in the habit of vifiting the mines of tin and copper in Cornwall, where captain Savery was well known, from his attempts to introduce his engine for the draining of mines, which, at that period, were nearly all of them at a ftand, for want of fome more powerful and cheap machines than hand-pumps or horfe-machines.

The captain was not fuccefsful in his attempts, principally becaufe he employed the direct action of the fteam upon the water, which either confined him to the height of 25 feet, or compelled him to employ fteam of a great elaftic force; in which cafe it became an indifpenfible condition, that the boiler and veffels fhould be very ftrong, as well as that a large quantity of fuel fhould be confumed, to produce fteam fufficiently denfe. It is probable that thefe inconveniencies may have early directed the thoughts of other ingenious men to the application of a pifton; but the difficulties of the undertaking feem to have retarded this purfuit for a confiderable time.

The firft fteam-engine with a pifton, made by Papin in 1707, which we have defcribed, was not at all calculated to remove the difficulties; and it is to Newcomen, and his affociate Cawley, that we are indebted for the application of a pifton with machinery, by which the indirect action of fteam a little ftronger than the atmofphere, or rather the direct action of the atmofphere upon a pifton, is made to act with fafety and effect againft the moft fevere preffures. It appears that they had brought their atmofpheric engine, about the year 1713, to a degree of perfection little inferior to thofe which are to be feen at prefent.

Principle of the Atmofpheric Engine.—To have an idea of its principles and mode of operation, fuppofe a very large fyringe or cylinder to be placed upright, and a pifton or plug inferted at the upper end, the ufual aperture being fuppofed to be at the lower extremity. If this laft aperture is open, the pifton will defcend by its own weight, neglecting the effect of friction at its circumference. But let it be imagined that the pifton is fupported by a counter-weight applied at the oppofite extremity, a lever, or by any other means: in this cafe the pifton will not defcend unlefs more weight is added to it.

Among the various ways of applying fuch a weight, there is one which confifts in exhaufting the air from the internal part of the cylinder, beneath the pifton: and if this is done, it is evident that the whole preffure of the atmofphere, amounting to about $14\frac{3}{4}$ pounds on every fquare inch, will become active upon the upper furface of the pifton. This method of gaining a great force was invented by the famous Otto Guericke: fee his Experimenta Magdeburgica, 1672. If the vacuum was to be produced by means of an air-pump on Guericke's plan, it muft be allowed that the labour of effecting it would be at leaft equal to that of any work which could be performed by the fubfequent defcent of the pifton; we muft therefore feek fome other means of producing fuch a vacuum. We have feen that in Savery's engine the operation of fteam is two-fold, namely, by the direct preffure from its elafticity, and by the indirect confequence of its condenfation, which affords a vacuum. This laft is the only principle employed in Newcomen's engine.

In order to produce the vacuum at pleafure in the interior capacity of the fyringe or cylinder, of which we have been fpeaking, it becomes requifite that feveral apertures fhould be formed at the bottom of the cylinder; one to communicate fteam from a boiler, and provided with a cock to cut off or open the communication at pleafure; another to admit at pleafure a jet of cold water, to condenfe the fteam during the interval in which the communication from the boiler is cut off; a third, provided with a drain-pipe, called the eduction-pipe, to carry off the condenfed fteam and injection-water; and laftly, a fmall lateral aperture, with a valve, to allow the efcape of the air, or permanently elaftic fluid, which will not condenfe by the application of cold water, or run off through the eduction-pipe: this laft is called the fnifting-clack.

By thefe provifions the operation of the cylinder is made to take place in the following manner. The pifton-rod is attached by a chain to the end of a long lever, at the oppofite end of which are fufpended the rods of the pumps which are to draw the water; and the weight of thefe rods exceeds the weight of the pifton fo much, as to draw the pifton up to the top of the cylinder. In this ftate, the fteam-cock is opened, and fteam iffues from the boiler; but being lefs than half the weight of common air, it rifes to the top of the cylinder, and expels the air through the fnifting-valve and eduction-pipe, of which the lower extremity is covered with a flap-valve, in a trough of water. When the noife of its efcape through thefe valves is heard, the fteam-cock is fhut, and the injection-pipe being opened, throws up a ftream of cold water in a jet within the cylinder, and ftrikes againft the bottom of the pifton: the fteam becomes immediately condenfed, and the preffure of the atmofphere forces the pifton down into the vacuum. Upon its progrefs downwards, the injection-pipe is clofed; and when it has arrived nearly at the bottom of the cylinder, the fteam-cock is again opened. The elaftic fteam fills the fmall fpace between the cylinder and the bottom, and its preffure on the under furface of the pifton affifts it to rife, and alfo affifts the eduction-water which remains in the bottom of the cylinder to pafs off through its pipe: the fteam alfo drives the air, or other elaftic fluid which will not condenfe, through the fnifting-valve. In this ftate, therefore, the fteam is fomewhat ftronger than the atmofphere, and rather more than counterpoifes its action on the upper furface of the pifton; in confequence, the pifton itfelf rifes by the action of the counter-weight, or pump-rods, at the oppofite end of the lever, and regains its original pofition at the top of the cylinder.

A fecond repetition of the procefs, namely, of fhutting off the fteam, and injecting cold water, caufes the pifton again to defcend, and in this manner the alternations may be continued without limit.

It is to be underftood, that the opening and fhutting of the fteam and injection-cocks are performed by apparatus fixed to the working lever, in fuch a manner as to ftrike the levers of thofe cocks at the precife inftant of time when their effects are required to be produced. The attendant has no other office to perform than that of keeping up the fire. To apply this power to the purpofe of raifing water for draining a mine, fuppofe a common fucking-pump placed in the pit to lift the water fifty yards high. If the pump is $7\frac{3}{4}$ inches bore, the column of water which muft be raifed when the rod or bucket of the pump is drawn up, will weigh 3060 lbs.; a chain being attached to the upper end of the rod of the pump, and fufpended from the extremity of the

long lever or working beam; and at the opposite extremity of the same beam another chain must be attached, to suspend the piston of the steam cylinder, which we have just described.

To give this piston a sufficient power of descent to make it draw up the water in the pump at the opposite end of the beam with celerity, the piston must be 22 inches in diameter; the area or surface of the piston will then be 380 square inches, $22 \times 22 = 484 \times .7854 = 380$. In this case, if each square inch is pressed with a weight of eight pounds, it will balance the weight of the water in the pumps within 20 pounds; for $380 \times 8 = 3040$, instead of 3060: but the pressure on each square inch will be considerably more than eight pounds; for, provided the vacuum was perfect within the cylinder, the pressure of the atmosphere would be $14\frac{3}{4}$ pounds; but the condensation of the steam in the cylinder is so far incomplete, that it leaves steam or vapour within the cylinder of some density. If the steam is cooled by the injection down to 140°, it will be seen by our first table, fourth column, that it will leave the cylinder filled with a vapour of an elastic force equal to 2 lbs. 13 oz. *per* square inch; which force acting beneath the piston, will deduct from the pressure of the atmosphere, and reduce the neat pressure on the piston to 11 lbs. $13\frac{1}{2}$oz. *per* square inch, as shewn by the last column. The excess of pressure beyond what is necessary to balance the weight of water is 3 lbs. *per* square inch, amounting, on the whole surface of the piston, to $(3 \times 380 =)$ 1140 lbs. nearly, a weight which is allowed to overcome the counter-weight which is to draw the piston up again, and the friction of the piston and pump-buckets, and make the engine move with a sufficient velocity, which will be more or less according to the state of the engine. But taking this velocity at 16 strokes *per* minute of six feet length each = 96 feet motion *per* minute, the pump of $7\frac{3}{4}$ inches diameter will raise 192 gallons *per* minute, or 182 hogsheads 13 gallons *per* hour. An engine of these dimensions is but a small one, yet it serves to shew the superiority of Newcomen's over Savery's engine, in principle. Savery's was an engine which really raised water by the force of steam; but Newcomen's raises water entirely by the pressure of the atmosphere, steam being employed merely as the most expeditious method of producing a void, into which the atmospherical pressure may impel the first mover of his machine. The elasticity of the steam is not the first mover. In the example of the engine we have just given to drain the same mine on Savery's plan, he must have employed steam of a pressure of 55 pounds *per* inch, and of a temperature of 325 degrees, to raise a column of water to a height of 125 feet: the condensation of this steam would be so great on coming in contact with water of only 50 degrees, that he would have found it scarcely practicable to have thrown up any considerable quantity.

We see also the great superiority of this new machine. There is no need of steam of great and dangerous elasticity, as it operates by means of very moderate heats, and consequently with much smaller quantities of fuel; and there are no other bounds to the power of this machine, than the strength of the materials of which it is composed. How deep soever a mine may be, a cylinder may be employed of such dimensions, that the pressure of the air on its piston may exceed in any degree the weight of the column of water to be raised; and lastly, this form of the machine renders it applicable to almost every mechanical purpose, because a skilful mechanic can readily find a method of converting the reciprocating motion of the working beam into a motion of any kind which may suit his purpose. Savery's engine could not admit of such an immediate application, and was restricted to raising of water.

Invention of Newcomen's Engine.—Respecting the invention of this engine, it was less a matter of original discovery, than of a combination of the inventions of others, *viz.* of Savery's invention of the means of producing a vacuum by the condensation of steam, with Otto Guericke's exhausted cylinder.

Savery made claim to the invention, and in consequence of the claim he made to the mode of condensation, as being a part of his patent, he was admitted by Newcomen and Cawley to an association with them in the patent which was granted in 1705, but it does not appear that they made any perfect engine until 1711.

Desaguliers, in his account of the invention, makes no mention of captain Savery being associated; but says "that Thomas Newcomen, ironmonger, and John Cawley, glazier, of Dartmouth, in the county of Southampton (Baptists), made several experiments in private about the year 1710, and in the latter end of the year 1711 made proposals to drain the water of a colliery at Griff, in Warwickshire, where the proprietors employed 500 horses at an expence of 900*l.* a year; but their invention not meeting with the reception they expected, in March following, through the acquaintance of Mr. Potter of Bromsgrove, in Worcestershire, they bargained to draw water for Mr. Back of Wolverhampton; where, after a great many laborious attempts, they did make the engine work: but not being either philosophers to understand the reason, or mathematicians enough to calculate the powers and proportion of the parts, they very luckily, by accident, found what they sought for.

"They were at a loss about the pumps, but being so near Birmingham, and having the assistance of so many admirable and ingenious workmen, they soon came to the method of making the pump-valves, clacks, and buckets, whereas they had but an imperfect notion of them before. One thing is very remarkable; as they at first were working, they were surprised to see the engine go several strokes, and very quick together, when, after a search, they found a hole in the piston, which let the cold water in to condense the steam in the inside of the cylinder, whereas before they had always done it on the outside. They used before to work with a buoy in the cylinder, inclosed in a pipe, which buoy rose when the steam was strong and opened the injection, and made a stroke; thereby they were capable of only giving six, eight, or ten strokes in a minute, till a boy, Humphrey Potter, who attended the engine, added (what he called *scoggan*) a catch, that the beam always opened, and then it would go 15 or 16 strokes a minute. But this being perplexed with catches and strings, Mr. Henry Beighton, in an engine he had built at Newcastle-upon-Tyne, in 1718, took them all away, but the beam itself, and supplied them in a much better manner." Since that time no very material alterations have been made in this species of engine, except the addition of the crank to make it turn mills.

The French authors have claimed this engine also as the invention of their countryman Papin, but without any reason: Papin had gained a knowledge of the expansive force of steam in his digester, and he invented the mode of working the pistons and cylinders by a vacuum and the pressure of the atmosphere; but he was not the first inventor of either of these, Otto Guericke and the marquis of Worcester having discovered the same things long before him; and further, he had no pretensions to claim Savery's discovery of the condensation of steam, upon which the engine of Newcomen depends.

Papin's Air Cylinder Engine.—Papin's invention of the cylinders

linders is by no means void of merit, we ſhall therefore briefly deſcribe it, and our readers will ſee how far it could have aſſiſted Newcomen, ſuppoſing him fully informed of it.

The firſt engine was for the purpoſe of tranſmitting the action of a water-wheel to a great diſtance, by means of air in pipes. Papin propoſed this principle enigmatically, as a new way of raiſing water, to the Royal Society in 1685; and after many ſolutions had been given by the Engliſh academicians, he ſhewed the real application and uſe of it, to raiſe water out of a mine by the power of a river at a conſiderable diſtance.

For this purpoſe, a water-wheel was to be placed in the river, to work the piſtons of two large cylinders of pumps, from the lower ends of each of which ſmall pipes were conducted down into the mine, to convey the air into ſmall cheſts or receivers, which were each furniſhed with a ſuction-pipe and a forcing-pipe, and valves to prevent the deſcent of the water. By the motion of the piſtons of the pumps, the air was to be alternately rarefied and compreſſed in theſe chambers; and thus he intended to draw water into the receptacles through the ſuction-pipes, and then force it up through the forcing-pipe; but he forgot that, in this method, the elaſticity of the air he employed would wholly defeat his end; for when the piſton of the pump was depreſſed, it would not compreſs the quantity of air contained in a long pipe ſufficiently to produce any ſenſible condenſation to force or raiſe water out of the receiver; nor, on the other hand, could a ſufficient rarefaction of the air be produced by the aſcent of the piſton to obtain any efficient ſuction in the receivers.

Papin afterwards made ſome alterations to obviate the objections which were urged by Dr. Hooke and other Engliſh philoſophers, and in 1688 he publiſhed another machine in the Acta Eruditorum, which is more complete, and is a moſt valuable invention for conveying the power of machines to a diſtance. Within theſe few years it has been employed in this country, though ſecretly, for a very important purpoſe.

In this method, the two pumps, which are worked by alternate cranks on the axle of the water-wheel, are provided with valves ſimilar to thoſe of an air-pump, and they draw air alternately from the conveyance-pipe which leads to the mine, ſo as to make a vacuum in the pipe. At the mine are placed two cylinders, with piſtons fitted into them; and a rope, which is faſtened to each of the piſtons, is wrapped ſeveral times round an axle or horizontal ſhaft, which is extended over both cylinders, and is put in motion by their piſtons.

Upon the middle of this axle is a large wheel, for the reception of a cord, which deſcends into the mine, and has at each end a bucket; therefore, by turning the axle firſt one way round, and then the other, the two buckets are alternately drawn up or lowered down in the mine, to draw either water or ore. The ropes from the piſton of the cylinders are wrapped round the axle in oppoſite directions; and when one piſton is preſſed down, it will draw the rope and turn the axle, which winding up, the other rope will draw up the piſton of the other cylinder. A ſingle conveyance-pipe leads from both the air-pumps at the water-wheel; but when the pipe arrives in the mine it divides into two branches, one for each cylinder; and at the interſection of theſe branches a double-paſſaged cock is placed, which will admit the air from either of the cylinders into the conveyance-pipe which leads to the air-pumps, or it will admit the atmoſpheric air into the cylinders; and theſe paſſages are opened alternately by the cock, ſo that whilſt the air from one cylinder is drawing off through the conveyance-pipe by the air-pumps, the atmoſpheric air ſhall have free entrance to the other cylinder.

The conſequence will be, that by the continual ſuction of the air-pumps a vacuum will be found under one piſton, and the preſſure of the atmoſphere will act to preſs it down in its cylinder; and by the rope which is attached to it and wound round the axle of the wheel, its deſcent will cauſe the axle and wheel to turn round and draw up the cord which paſſes over the wheel at one ſide, ſo as to raiſe up one bucket in the mine and lower down the other; but during the deſcent of this piſton, the other piſton is freely at liberty to be drawn up in its cylinder, becauſe the cock admits the atmoſpheric air into the ſame. When the piſton under which the vacuum has been made is preſſed down to the bottom of its cylinder, the other piſton will be drawn up to the top of its cylinder, by its rope winding upon the axle. In this ſtate the cock is turned the other way, and will then draw off the air from the cylinder in which the piſton is at the top, and admit freſh air into the cylinder in which the piſton is at the bottom. This will cauſe the axle and wheel to turn round in an oppoſite direction to what it did before, and draw up the oppoſite bucket from the mine.

In this way a conſtant reciprocation of the motion of the axle is kept up, and the power of the water-wheel is tranſmitted ſimply by the conveyance-pipe to any required diſtance, where, by uſing a larger or ſmaller cylinder, it may be made to act with any required force. The inventor propoſed this method to be uſed to convey the power of the water-wheels in the Seine to work pumps at Verſailles, inſtead of the cumberſome machinery employed at Marly for conveying the motion; and it is rather ſurpriſing that ſo ſimple and advantageous a method ſhould have remained ſo long neglected and unknown, that even now, when its effects are publicly exhibited, the means are not known. The only improvement upon the method of Papin, which it is neceſſary to put in practice, is to have a receiver or air-chamber near the cylinders, to be kept exhauſted by the pumps; and this being of ſufficient capacity the air will ruſh into it, and be taken away from beneath the piſton the inſtant the cock is opened; whereas without it, it would be drawn off more ſlowly by the pumps. If the conveyance-pipe is made of large dimenſions, it will effect the ſame end moſt completely.

Deſcription of the Atmoſpheric Engine.—Our readers being now acquainted with the principle of Newcomen's engine, we ſhall proceed to deſcribe it in the ſtate to which it was brought by Mr. Beighton, and which for more than half a century was the ſtandard engine for raiſing water from mines. See the perſpective view in *Plate* II. *fig.* 1. which repreſents the engine complete, the front wall of the houſe being ſuppoſed to be removed to ſhew the interior.

A, the fire-place under the boiler for raiſing the ſteam, and the aſh-hole below it.

B, the boiler, made of iron plates: it is filled with water about three feet above the bottom.

C, the ſteam-pipe, through which the ſteam paſſes from the boiler into the receiver.

D, the receiver, a cloſe iron veſſel or box, in which is the regulator or ſteam-cock, which opens and ſhuts the hole of communication with the cylinder at each ſtroke.

E is the communication-pipe, between the receiver and the cylinder; it riſes five or ſix inches up in the inſide of the cylinder above the bottom, to prevent the injected water from deſcending into the receiver.

F, the cylinder of caſt-iron, about ten feet long, bored ſmooth in the inſide; it has a broad flanch in the middle, on the outſide, by which it is ſupported when hung between the cylinder-beams, which extend acroſs the houſe, and are let into the ſide-walls.

G, the piſton, made to fit the cylinder exactly, but with liberty to ſlide up and down; it has a flanch riſing four or five inches upon its upper ſurface, between which and the ſide of the cylinder a quantity of junk or oakum is ſtuffed, and kept down by weights, to prevent the entrance of air or water, and the eſcape of ſteam.

H, the chain and piſton-ſhank, by which it is connected to the working beam by an arc of a circle.

I I, the working beam or lever, working on its centre, in the manner of a ſcale-beam; it is made of two or more large logs of timber, bent together at each end, and kept at the diſtance of eight or nine inches from each other in the middle by the gudgeon or centre, as repreſented in the plate. The arch-heads I, I, at the ends of the beam, are for giving a perpendicular direction to the chains of the piſton and pump-rods, which are ſuſpended at the oppoſite ends.

K, the pump-rod, which works in the great ſucking-pump L, and draws the water from the bottom of the mine to the ſurface.

M, a ciſtern, into which the water drawn out of the pit is conducted by a trough, ſo as to keep it always full, and the ſuperfluous water is carried off by another trough.

N, the jack-head pump, which is a ſmaller ſucking-pump, wrought by a ſmall lever or working beam, by means of a chain connected to the great beam or lever near the arch *g*, at the inner end; and the rod of the pump N is ſuſpended by a chain at the outer end. This pump commonly ſtands near the corner of the front of the houſe, and raiſes a column of water up to the ciſtern O, into which it is conducted by a trough.

O, the jack-head ciſtern, for ſupplying the injection; it is always kept full by the pump N, and is fixed ſo high above the cylinder bottom, as to give the jet of injection a ſufficient velocity into the cylinder when the cock is opened. This ciſtern has a waſte-pipe on the oppoſite ſide for conveying away the ſuperfluous water.

P P, the injection-pipe, of two or three inches diameter, which deſcends from the ciſtern, O, to the injection-cock *r*, after paſſing which it turns up in a curve at the lower end, and enters the cylinder bottom. It has a thin plate of iron ſcrewed upon the end *d*, which is within the cylinder, with three or four ajutage holes in it, to cauſe the jet of cold water from the jack-head ciſtern to fly up in as many ſtreams againſt the under ſurface of the piſton, and condenſe the ſteam contained in the cylinder each ſtroke, when the injection-cock is open.

e, a valve upon the upper end of the injection-pipe, which is ſhut, to prevent waſte of water by leakage when the engine ſtands ſtill; but before the engine is ſet to work, this valve muſt be lifted up, and kept open by a ſtring.

f, a ſmall pipe, which branches off from the injection-pipe, and has a cock to ſupply the piſton with a little water to keep it air-tight.

Q, the working plug, ſuſpended by a chain to the ſmall arch, *g*, of the working beam. It is uſually a heavy piece of timber, with a ſlit vertically down its middle, and holes bored horizontally through it to receive pins, for the purpoſe of opening and ſhutting the injection and ſteam-cocks, as it aſcends and deſcends by the motion of the working beam.

h, the handle of the ſteam-cock or regulator. It is fixed to the regulator by a ſpindle, which comes up through the top of the receiver. The regulator itſelf is a ſectorial plate of braſs, ſhaped like a fan, which is moved horizontally by the handle *h*, and opens or ſhuts the communication at the lower end of the pipe E, within the receiver. It is repreſented ſeparately in the plate by *fig.* 2.

i i, the ſpanner, which is a long rod or bar of iron, for communicating motion to the handle of the regulator, to which it is fixed by means of a ſlit in the latter, and ſome pins put through to faſten it.

k l, the vibrating lever, called the tumbling-bob, or the Y, having the weight *k* at one end, and the two forked legs at the other end, like the letter ⅄ turned. It is fixed to an horizontal axis, moveable about its centre pins, or pivots, *m*, *n*, and is put in motion by means of the two ſhanks *o*, *p*, fixed to the ſame axis, which are alternately raiſed and depreſſed by means of two pins in the working plug, and the bob or weight at the top of the Y is thrown backwards and forwards; one pin on the outſide, depreſſing the ſhank *o*, throws the loaded end, *k*, of the Y from the cylinder into the poſition repreſented in the plate, and cauſes the leg, *l*, of the fork of the Y to ſtrike againſt the end of the ſpanner, which forcing back the handle of the regulator or ſteam-cock opens the communication, and permits the ſteam to fly into the cylinder. The piſton immediately riſes by the weight of the pump-rod, on the admiſſion of the ſteam: the motion of the working beam, I I, alſo raiſes the working plug; and another pin, which goes through the ſlit, raiſes the ſhank, *p*, of the axis, which throws the end, *k*, of the Y towards the cylinder, and the leg of the fork, ſtriking the end of the ſpanner, forces it forwards, and ſhuts the regulator or ſteam-cock.

q r is the lever for opening and ſhutting the injection-cock, called the F. It has a rack or toothed ſector fixed upon its axis, which takes the teeth of a pinion, fixed on the top of the plug or key of the injection-cock. When the working plug has aſcended nearly to its greateſt height, and ſhut the regulator, as above deſcribed, a pin catches the end, *q*, of the F, and raiſes it up, which opens the injection-cock, and admits a jet of cold water to fly into the cylinder, and condenſing the ſteam, makes a vacuum within. Then the preſſure of the atmoſphere, forcing down the piſton into the cylinder, cauſes the plug-frame to deſcend, and another pin fixed in it catches the end of the lever, *q*, in its deſcent, and by preſſing it down ſhuts the injection-cock; at the ſame time the regulator is opened to admit ſteam, and ſo on alternately; that when the regulator is ſhut, the injection-cock ſhall be open, and when the former is open, the latter ſhall be ſhut.

R, the eduction-pipe, to convey away the water which is injected into the cylinder at each ſtroke; its upper end is even with the cylinder bottom, and its lower end has a lid or cover, moveable on a hinge, which ſerves as a valve to let out the injected water, and ſhuts cloſe each ſtroke of the engine, to prevent the water being forced up again when the vacuum is made.

S, the hot-well, which is a ſmall ciſtern made of planks, to receive all the waſte water from the cylinder, and keep it in reſerve for feeding the boiler, to ſupply the waſte occaſioned by the continual evaporation of the ſteam.

T, the feeding-pipe, to ſupply the boiler with water from the hot-well. It has a cock to let in a large or ſmall quantity of water, as occaſion requires, to make up for what is evaporated: it goes nearly down to the boiler bottom, ſo that the lower end is always immerſed in water.

U, two gauge-cocks, in the upper ends of two pipes which deſcend into the boiler; one is deeper than the other: their uſe is to try when a proper quantity of water is in the boiler, for upon opening the cocks, if one gives ſteam and the other water, it is right, becauſe the intended level of the water in the boiler is between the ends of the two. If they both give water there is too much.

W is the man-hole: it is a plate which is ſcrewed over

a hole on the fide of the boiler, to allow a paffage into it for the convenience of cleaning or repairing.

X, the fteam-clack or puppet-valve, which is a brafs valve, on the top of the pipe opening into the boiler, to let off the fteam when it is too ftrong. It is loaded with lead at the rate of one pound to an inch fquare; and when the fteam is nearly ftrong enough to keep it open, it will do for the working of the engine.

s, the fnifting-valve, by which, at every afcent of the pifton, the air is difcharged from the cylinder which was admitted with the injection, and would otherwife obftruct the due operation of the engine.

t t, the cylinder beams, which are ftrong girders going through the houfe, for fupporting or rather keeping down the cylinder.

v, the cylinder cup of lead furrounding the top of the cylinder, to prevent the water upon the pifton from flafhing over when it rifes too high.

w, the wafte-pipe, which conducts the fuperfluous water from the top of the cylinder to the hot-well.

x x, iron bars, called the catch-pins, fixed horizontally through each arch-head to ftrike the floor, and prevent the beam defcending too low, in cafe the chains at either end fhould break, or if the engine makes too long a ftroke.

y y, two ftrong wooden fprings, to weaken the blow given by the catch-pins, when the ftroke is too long.

z z, two friction-wheels or fectors, on which the gudgeons, or centres of the great beam, are fupported; they are the third or fourth part of a circle, and move a little each way as the beam vibrates.

Their ufe is to diminifh the friction of the axis, which being neceffarily very large for fo heavy a lever, would otherwife be very great.

Operation of the Atmofpheric Engine.—When this engine is to be fet to work, the boiler muft be filled about two or three feet deep with water, and a large fire made under it; and when the fteam is heated to be of fufficient ftrength to exert a preffure of about one pound beneath each fquare inch of the fafety-valve, it will lift up the valve and efcape. The water in the boiler being fuppofed to be in a ftrong ftate of ebullition, and the fteam iffuing by the fafety-valve, we will confider the machine in a ftate of reft, having both the fteam-cock and injection-cock fhut. The refting pofition or attitude of the machine is fuch as appears in the drawing, the pump-rods, K, preponderating by their weight; and the great pifton being drawn to the top of the cylinder.

The man who attends the engine depreffes the handle *p*, fo as to throw the tumbling-bob into the pofition of the figure; and the leg of the fork thrufting back the fpanner *i i*, opens the regulators or fteam-cock, when the fteam from the boiler immediately rufhes in, and flying all over the cylinder, will mix with the air: much will be condenfed by the cold furface of the cylinder and pifton, and the water produced from it will trickle down the fides, and run off at the eduction-pipe, R, as foon as any quantity is accumulated. This condenfation and wafte of fteam will continue, till the whole cylinder and pifton are made as hot as boiling water.

When this happens, the fteam will begin to open the fnifting-valve *s*, and iffue through the pipe; at firft flowly and very cloudy, being mixed with much air, the cloudy appearance of fteam being always owing to its mixture with common air. The blaft at *s* will grow ftronger by degrees, and more tranfparent, having already carried off the greateft part of the common air which filled the cylinder. We fuppofed, at firft, that the water was boiling brifkly, fo that the fteam was iffuing by the fafety-valve, which is in the top of the boiler. The opening of the fteam-cock puts an end to this at once, becaufe the cold cylinder draws off the fteam from the boiler with aftonifhing rapidity, until it becomes heated fo as not to condenfe.

When the manager of the engine perceives that not only the blaft at the fnifting-valve is ftrong and fteady, but that the boiler is fully fupplied with fteam of a proper ftrength, which appears by the renewal of the difcharge at the fafety-valve, the engine is ready for ftarting. He now lifts up the handle *o* or *p*, till the tumbling-bob, Y, falls over the perpendicular towards the cylinder, and its leg ftriking the crofs-pin of the fpanner, *i*, draws it forwards, and fhuts the fteam-regulator; at the fame inftant he lifts up the handle, *q*, of the F, which opens the injection-cock. The preffure of the column of water in the injection-pipe, P, immediately forces fome water through the fpout *d*, by the jets.

The cold water coming in contact with fome of the pure vapour, which now fills the cylinder, condenfes it, and thus makes a partial void, into which the more diftant fteam immediately expands; and by this very expanfion its capacity for heat is increafed; or, in other words, as it grows cold, it abftracts the heat more powerfully from the fteam fituated immediately beyond it.

In this expanfion and refrigeration the fteam is itfelf partly condenfed or converted into water, and leaves a void, into which the circumjacent fteam immediately expands, and produces the fame effect on the fteam beyond it: and thus it happens, that the abftraction of a fmall quantity of heat from an inconfiderable mafs of fteam produces a condenfation throughout a cylinder which is very extenfive.

What remains in the cylinder no longer balances the atmofpheric preffure on the furface of the water in the injection-ciftern, and, therefore, the water fpouts rapidly through the holes *d*, by the joint action of the column P, and the unbalanced preffure of the atmofphere; at the fame time the fnifting-valve *s*, and the eduction-valve R, are fhut by the external preffure of the atmofphere, and prevent the entrance of air or water into the cylinder. The velocity of the injection-water muft therefore rapidly increafe, and the jets dafh againft the bottom of the pifton, and be fcattered through the whole capacity of the cylinder. In a very fhort fpace of time therefrom, the condenfation of the fteam becomes univerfal, and the elafticity of what remains is very fmall. The whole preffure of the atmofphere, therefore, being exerted on the upper furface of the pifton, while there is hardly any on its under fide, if the load on the outer end of the working-beam is inferior to this preffure, it muft yield to it. The pifton G muft defcend, and the pump-pifton *k* muft afcend, bringing along with it the water of the mine; but the motion does not begin at the inftant the injection is made.

The pifton was kept at top by the preponderancy of the outer end of the working beam and the load of water in the pumps, and it muft remain there, till the difference between the elafticity of the fteam below it, and the preffure of the atmofphere, exceed this preponderancy. There muft, therefore, be a fmall fpace of time between the beginning of the condenfation and the beginning of the motion: this is very fmall, not exceeding the third or fourth part of a fecond; but it may be very diftinctly obferved by an attentive fpectator, who may perceive, that the inftant the injection-cock is opened, if the cylinder has the flighteft yielding in its fufpenfion, it will heave upwards a little by the preffure of the air on the bottom. Its own weight is not at all

equal to this preſſure; and inſtead of its being neceſſary to ſupport it by a ſtrong floor, it muſt be kept down by large beams, loaded at the end with heavy walls. This heaving of the cylinder ſhews the inſtantaneous commencement of the condenſation; and it is not till after this has paſſed, that the piſton is ſeen to ſtart, and begins to deſcend.

The motion muſt continue till the great piſton reaches the bottom of the cylinder, becauſe it is not like the motion which would take place in a cylinder of air rarefied to the ſame degree. In this latter caſe, the impelling force would be continually diminiſhed, becauſe the capacity of the cylinder diminiſhing by the deſcent of the piſton, the air in it would continually become more denſe and elaſtic, until the piſton would ſtop at a certain height, where the elaſticity of the included air, together with the load at K, would balance the atmoſpherical preſſure on the piſton. But when the contents of the cylinder are pure vapour, and the continued ſtream of injected cold water keeps down its temperature to the ſame pitch as at the beginning, the elaſticity of the remaining ſteam can never increaſe by the deſcent of the piſton, nor exceed what correſponds to the temperature, according to our table. The impelling or accelerating force, therefore, remains the ſame; and the deſcent of the piſton will be accelerated almoſt uniformly, unleſs there is an increaſe of reſiſtance, ariſing from the nature of the work performed by the other end of the beam. And it may be frequently obſerved in a good ſteam-engine, where every part is air-tight, that if the cylinder has been completely purged of common air before the ſteam-cock is ſhut, and if none has entered ſince, the piſton will deſcend to the very bottom of the cylinder. It ſometimes happens, by the great pump drawing air, or ſome part of the communication-chains giving way, that the piſton deſcends with ſuch violence as to beat out the bottom of the cylinder with the blow, and it is to prevent this accident that the catch-pins are applied at the end of the beam.

When the manager ſees the piſton as low as he thinks proper, he ſhuts the injection-cock, by depreſſing the lever *q*; and at the ſame time he opens the regulator, by forcing down the handle *o*, which overſets the tumbling-bob, and its leg catching the croſs-pin of the ſpanner, *i*, opens the regulator.

The ſteam has been accumulating above the water in the boiler during the whole time of the piſton's deſcent. The moment, therefore, that the ſteam-cock is opened, the ſteam, having an elaſticity of rather more than one pound *per* ſquare inch greater than that of the air, ruſhes into the cylinder, when it immediately blows open the ſnifting-valves, and aſſiſts the water which had come in by the former injection, and what aroſe from the condenſed ſteam, to deſcend by its own weight through the eduction-pipe S, and open the valve to run out into the hot-well R.

This water is nearly boiling-hot, or at leaſt its ſurface; for while lying in the bottom of the cylinder, it will condenſe ſteam till it acquires this temperature, and therefore cannot run down till it will condenſe no more. There is a cauſe of ſome waſte of ſteam at its firſt admiſſion, in order to heat the inſide of the cylinder, and the injected water, to the boiling temperature; but the ſpace being ſmall, and the whole being already very warm, it is very ſoon done; and when things are properly conſtructed, little more is wanted than what will warm the cylinder; for the eduction-pipe is made of large dimenſions, and receives ſome of the injection-water even during the deſcent of the piſton, and this portion will be removed out of the way of the ſteam.

The firſt effect of the entering ſteam is of great ſervice; it drives out of the cylinder the vapour which it finds there. This is ſeldom pure ſteam, or watery vapour, becauſe all water contains a quantity of air in a ſtate of chemical union; but the union is only feeble, and a boiling heat is ſufficient for diſengaging the greateſt part of it, by increaſing its elaſticity. It may alſo be diſengaged by ſimply removing the external preſſure of the atmoſphere. This is clearly ſeen when we expoſe a glaſs of water in an exhauſted receiver. Therefore the ſmall ſpace below the piſton contains watery vapour, mixed with all the air which had been diſengaged from the water in the boiler by ebullition, and all that was ſeparated from the injection-water by the diminution of external preſſure, in addition to any which may enter by leakage.

Let us now conſider the ſtate of the piſton, when ſetting out on its return; as it is evident that it will ſtart, or begin to riſe by the counter-weight, the moment the ſteam-cock is opened; for at that inſtant the exceſs of atmoſpherical preſſure, by which it was kept down in oppoſition to the preponderancy of the outer end of the beam, is diminiſhed. At the firſt inſtant of the return of the pump-rods, they draw up the piſton with great violence, all the weight of the water in the pumps acting in addition to the counter-weight; but the falling of the lower valves in the pumps, after an inch or two of motion, arreſts the further deſcent of the water, and bears the weight of the column of water; and after this the piſton will riſe gradually by the action of the counter-weight.

The action of the counter-weight is very different in the two motions of the engine; for while the engine is making a working ſtroke, it is lifting not only the column of water in the pump, but the abſolute weight of the bucket-rods alſo; and while the pump-rods are deſcending, there is a diminution of the counter-weight, by the whole weight loſt by the immerſion of the rod in water. The wooden rods which are generally uſed being ſoaked in water, and joined by iron ſtraps, are heavier, and but a little heavier, than water, and they are generally about one-third of the bulk of the water in the pumps.

By this counter-weight the piſton is drawn upwards; and it would even riſe, although the ſteam which is admitted was not quite ſo elaſtic as common air.

Suppoſe the mercury in the barometer to ſtand at 30 inches, and that the preponderancy at the outer end of the beam was equal to $\frac{1}{8}$th of the preſſure of the air on the piſton, the piſton would not riſe until the elaſticity of the ſteam was equal to $30 - \frac{1}{8}$, that is, to $26\frac{1}{4}$ inches nearly; but if the ſteam was juſt equal to this quantity, the piſton would riſe as faſt as the ſteam of that denſity could be ſupplied to the cylinder through the ſteam-pipe; and on this ſuppoſition, the velocity of the aſcent would depend on the velocity of that ſupply. But this is not the caſe in practice, becauſe the ſteam muſt be ſtronger than the air, in order to blow out and diſcharge the air; it will therefore enter the cylinder without any effort on the piſton to draw or ſuck it in. At the ſame time, the counter-weight muſt not be ſo great as to draw up the piſton with that force which will cauſe a ſuction within the cylinder greater than the ſteam-pipe can ſupply, or it would diminiſh the preſſure of the ſteam within the cylinder lower than the atmoſphere, and prevent it from ſnifting or blowing out the air.

In filling the cylinder with ſteam, it will require a much more copious ſupply of ſteam than merely to fill up the ſpace left by the aſcent of the piſton; for as the deſcent of the piſton was only in conſequence of the vacuum occaſioned by the interior of the cylinder being ſufficiently cooled to condenſe the ſteam, this cooled ſurface muſt be again preſented to the ſteam during the riſe of the

piston, and must condense steam a second time. The piston cannot rise another inch, till that part of the cylinder which the piston has already quitted has been warmed up to the boiling point, and much steam must be expended in this warming; for the inner surface of the cylinder must not only be raised to the heat of boiling water while the piston rises, but must also be made perfectly dry; and the film of water left on it by the ascending piston must be completely evaporated, otherwise it will continue to condense steam.

On this account, although the counter-weight is not necessary to suck in the steam, the moving force during the ascent of the piston must be considered as resulting chiefly, if not solely, from the preponderating weight of the great pump-rods; and this force is expended partly in returning the steam-piston to the top of the cylinder, where it may be again pressed down by the air, and make another working stroke by raising the pump-rods; and partly in returning the pump-buckets into their places at the bottom of their respective working barrels, in order that they may also make another working stroke. This latter requires force independent of the friction and inertia of the moving parts; for each bucket must be pushed down through the water in the barrel, which must lift up and rise through the valves in the bucket with a velocity proportioned to the velocity of the bucket, in the same degree as the area of the pump-barrel is proportioned to the opening of the valves through which the water must pass.

From this general consideration of the ascent of the piston, we may see that the motion differs greatly from the descent; it can hardly be supposed to accelerate, even if the steam was supplied to the cylinder in ever such quantity: for the resistance to the descent of the pump-bucket is the same with the weight of the column of water, which would cause water to flow through the valves of the buckets with the velocity with which it really rises through them, and this resistance must therefore increase as the square of that velocity increases; that is, as the square of the velocity with which the bucket descends. Independent of the force of friction, and the weight of the valves, the velocity of descent through the water must soon become a maximum, and the motion will become uniform. Accordingly, any one who observes with attention the working of a steam-engine, will see that the rise of the piston and descent of the pump-rods are extremely uniform, whereas the working stroke is very sensibly accelerated.

These two motions complete the period of the operation, and the whole may be repeated by shutting the regulator, and opening the injection-cock whenever the piston has attained the proper height. For the first two or three strokes, the opening and shutting of the cocks are performed by the attendant; but when he has thus ascertained that all parts are in order, he puts pins into the holes of the plug-frame, and the motion of the engine will then actuate its own machinery, and perform its reciprocations with greater regularity than can be done by hand.

Particulars of different Parts of the Atmospheric Engine.— We shall now pay some attention to the construction of the parts of this engine, and notice some further particulars.

The furnace or fire-place should not have the grate-bars so close as to prevent the free admission of air, nor so open as to let the coals fall through. About two inches are sufficient for the distance betwixt the bars. The height from the bars to the bottom of the boiler in the centre should not be more than two feet, and the concavity or rise of the bottom in the centre about one foot.

The size of the furnace depends upon the size of the boiler; but in every case the ash-hole ought to be capacious, to admit the air. If the flame is conducted in a flue or chimney round the outside of the boiler, or in a pipe round the inside of it, it ought to be gradually diminished from its entrance at the furnace to its egress at the chimney; and the section of the chimney at that place should not exceed the section of the flue or pipe, and should also be somewhat less at the chimney-top.

The boiler or vessel, in which the steam is made by the force of fire, may be formed of iron plates, or copper, or of cast-iron, the bottom being of such materials as can withstand the effects of the fire, and have sufficient strength to retain the elastic force of the steam. It may be considered as consisting of two parts; an upper part, which is exposed to the steam, and an under part, which is exposed to the fire. The form of the latter should be such as to receive the full force of the fire in the most advantageous manner, so that a certain quantity of fuel may have the greatest possible effect in heating and evaporating the water; which is best done by making the sides cylindrical, and the bottom a little concave, and then conducting the flame by an iron flue or pipe round the inside of the boiler, beneath the surface of the water, before it reaches the chimney. For by this means, after the fire in the furnace has heated the water by its effect on the bottom, the flame heats it again by the pipe being wholly included in the water, and having every part of its surface in contact with it; which is preferable to carrying it in a flue or chimney round the outside of the boiler, as a third or a half of the surface of the flame only can be in contact with the boiler, the other being spent upon the brick-work. This cylindric lower part may be less in its diameter than the upper part, and may contain from three to five feet perpendicular height of water in it.

The upper part of the boiler is best made hemispherical for resisting the elasticity of the steam; yet any other form may do, provided it be of sufficient strength for the purpose.

The quick going of the engine depends much upon the capaciousness of the boiler-top; for if it be too small, it requires the steam to be heated to a greater degree to increase its elastic force sufficiently to work the engine, and then the condensation on entering the cylinder will be greater. If the top is so capacious as to contain eight or ten times the quantity of steam used at each stroke, it will require no more fire to preserve its elasticity than is sufficient to keep the water in a proper state of boiling; this, therefore, is a sufficient size for the boiler-top.

It is usual to place a damper, or iron slider, in the chimney, or in the flue leading into the chimney; and this has a chain or lever, by which the attendant can regulate the aperture of the chimney, and consequently the draught of the fire, so as to keep the steam to a great regularity: for it is evident, that when the engine works slowly, it will require less steam and fuel than when working rapidly; and without the damper, the engine would be constantly exposed to an excess or deficiency in the supply of steam. The boiler is, in some engines, placed immediately beneath the cylinder, the same as represented in *Plate* III.; and then the regulator is placed immediately within the boiler, and acts against the under surface of its top, in the same manner as in the first engine of captain Savery, who invented the regulator.

It was a subsequent improvement of Newcomen's engine to remove the boiler from immediately beneath the cylinder to a small shed on the outside of the engine-house; by this means the height of the building is considerably reduced; and as the wall which supports the beam-centre does not require to be carried to so great a height, it is more enabled to withstand the violent shocks to which it is constantly subjected from the working of the engine. Another and

ftill greater advantage is, that two boilers can be employed; or when the original boiler requires to be repaired or renewed, it can be replaced by erecting another at one fide, and carrying another fteam-pipe to the fteam-box: in this way the working of the engine can be continued without any ftoppage; a circumftance of the greateft importance where the water muft be conftantly kept drained.

In either cafe, whether the regulator is placed in the boiler itfelf, or in the fteam-box beneath the cylinder, it is conftructed in the manner reprefented in *Plate* II. *fig.* 2. It is a flat plate of brafs, in fhape refembling a fan, the upper furface of which applies itfelf exactly to the whole circumference of the orifice of the fteam-pipe, and completely excludes the fteam from the cylinder, being moveable round an upright axis Q, which is accurately fitted into a conical focket coming through the lid of the fteam-box. It can be turned afide by a lever, or handle, on the upper end of this axis, fo as to uncover or open the paffage. The profile fhews that, in the fection of this plate, there is a protuberance in the middle. This refts on a ftrong flat fpring, fixed below it, acrofs the mouth of the fteam-pipe, which fpring preffes it ftrongly towards the fteam-pipe, caufing it to apply very clofe, and the protuberance flides along the fpring, while the regulator turns to the right or left. Both the handle of the regulator, and the end of the rod or fpanner *i i*, *fig.* 1, are pierced with feveral holes, and a pin is put through them, which unites them by a joint. The motion of the handle of the regulator may be increafed or diminifhed, by choofing for the joint a hole near to the axis or remote from it, and the exact pofition at which the regulator is to ftop on both fides is determined by pins ftuck in a horizontal bar, on which the end of the handle refts.

The tumbling-bob of the Y has a long leather checkftrap faftened to it by the middle, and the two ends of the ftrap are faftened to the beams above it in fuch a manner, that the lump may be alternately catched, and held up to the right and left of the perpendicular. By adjufting the length of the two parts of the ftrap, the Y may be ftopped in any defired pofition. The two legs of the fork fpread out from each other, and alfo from the line of the ftalk, thus ⅄, and they are of fuch length as to reach the horizontal pin, which croffes the fork or ftirrup of the fpanner below.

Now, fuppofe the pin of the fpanner hanging perpendicularly beneath the axis, and the ftalk of the Y alfo held perpendicular, carry it a little outward from the cylinder, and then let it go, it will fall farther out of its weight, without affecting the ftirrup of the fpanner, till the inner leg ftrikes on the horizontal pin of the ftirrup, and then it pufhes the pin of the ftirrup and the fpanner towards the cylinder, and fhuts the regulator. It thus fets the regulator in motion with a fmart jerk, which is an effectual way of overcoming the cohefion and friction of the regulator againft the mouth of the fteam-pipe. This pufh is adjufted to the proper length by the check-ftrap, which ftops the Y when it has gone far enough. If we now take hold of the ftalk of the Y, and move it up to the perpendicular, the width between its claws is fuch as to permit this motion, and fomething more, without affecting the ftirrup. But when pufhed ftill nearer to the cylinder, it tumbles fuddenly towards it by its own weight, and then the other leg of the fork ftrikes the pin of the ftirrup of the fpanner in the oppofite direction, till the bob is checked by the ftrap.

Thus, by the motion of the Y, the regulator is open and fhut fuddenly. This opening and fhutting of the fteam-paffage are executed in the precife moment that is proper, by placing the pins in the plug-beam, which act upon the handles *o* and *p*, at a proper height. For this reafon, it is pierced through with a great number of holes, that the places of thefe pins may be varied at pleafure: this, and a proper curvature of the handles *o* and *p*, make the adjuftment as nice as we pleafe.

In the fame manner the motions of the injection-cock are alfo adjufted to act at the precife moment that is proper for them. The different pins are fo placed in the plug-frame, that the fteam-cock may be completely fhut before the injection-cock is opened. The inherent motion of the machine, or the momentum of its parts, will give a fmall addition to the afcent of the pifton, without expending fteam all the while, and by leaving the fteam rather lefs elaftic than before, the fubfequent defcent of the pifton is promoted.

The injection-cock is frequently provided with a tumbling-bob, to make it open fuddenly. This is an arm extending from the centre of the F, or lever *q*, upon which the toothed fector is fixed, and having at its extremity a fufficient weight to open the cock in an inftant. When this weight is lifted up to its utmoft, the cock is fhut, and in this pofition the weight is detained by a fmall latch, which is lifted up by a pin in the plug-frame, at the moment when the pifton arrives at the top of the cylinder, and thus releafing the weight, it falls all at once, and opens the cock in an inftant; but when the pifton defcends nearly to the bottom, another pin in the plug-frame takes the handle of the fector, and gradually clofing the cock, raifes the weight till the latch detains it, which happens when the pifton is quite at the bottom of its motion.

The injection-cock ought to be opened fuddenly; but there is much propriety in clofing it gradually: for after the firft dafh of the cold water againft the bottom of the pifton, the condenfation is nearly complete, and very little more water is neceffary, although a continual acceffion of fome is abfolutely required for completing the condenfation as the capacity of the cylinder diminifhes, and the water which is already injected becomes warmed. It is the continuance of this fmall injection which prevents the vapour in the cylinder becoming more denfe as the pifton defcends.

The effect of the injection in condenfing the fteam in the cylinder depends upon the height of the refervoir and diameter of the ajutage: if the engine makes a fix-feet ftroke, then the jack-head ciftern fhould be at leaft twelve feet perpendicular above the top of the cylinder. The fize of the ajutage muft depend upon the capacity of the cylinder, as we fhall fhew by a table; but if the cylinder be very large, it is common to have three or four fmall holes rather than one large one, in order that the jet may be difperfed the more effectually through the whole capacity of the cylinder. The injection-pipe, or pipe of conduct, fhould be fufficiently large to fupply the injection freely with water. The injection-ciftern is the common fource from which all the parts of the machine receive their refpective fupplies of cold water. In the firft place, the fmall branch *f*, which proceeds from the pipe P, immediately below the ciftern, and is conducted to the top of the cylinder, has a cock at the end, which muft be fo adjufted, that no more water will run from it than what will keep a conftant fupply of a few inches of water above the pifton to keep it tight. Every time the pifton comes to the top of the cylinder it will bring the water along with it, and the furplus of its evaporation and leakage runs off by a wafte-pipe *w*. This water neceffarily becomes almoft boiling-hot, and it was thought proper to employ its overplus for fupplying the wafte of the boiler. This was accordingly practifed for fome time; but Mr. Beighton improved this economical thought by fupplying the boiler from the eduction-pipe S, the water of which

coming from the cylinder, muſt be ſtill hotter than that above the piſton.

This contrivance required attention to ſeveral circumſtances, which will be eaſily underſtood by conſidering the perſpective view. The eduction-pipe comes out of the bottom of the cylinder in an inclined direction, and deſcends into the hot-well R, where it turns up, and is covered with a valve: in the perſpective view may be obſerved an upright pipe T, which goes through the head of the boiler, and reaches to within a few inches of its bottom. This pipe is called the feeder, and riſes about three or four feet above the ſurface of the water in the boiler: it is open at both ends, and has a horizontal branch from its upper end, communicating with the hot-well R. This communicating branch has a cock, by which its paſſage may be diminiſhed at pleaſure. Now, ſuppoſing the ſteam in the boiler to be very ſtrong, it will cauſe the boiling water to riſe in the feeding-pipe T, and paſſing along this branch, to riſe alſo in the hot-well, and run over. The height of the ſurface of water in the hot-well, above the ſurface of the water in the boiler, is ſuch, that the ſteam is never ſtrong enough to produce this effect; but, on the contrary, the water in the hot-well will run off by the branch, and go down into the boiler by the feeding pipe, as faſt as the opening of the cock will admit. Theſe things being underſtood, let us ſuppoſe a quantity of injected water lying at the bottom of the cylinder, it will run into the eduction-pipe S, and opening the valve in the bottom, will flow into the hot-well. By properly adjuſting the cock on the branch of T, the boiler may be ſupplied with water as faſt as the waſte in ſteam-engine requires.

The ſmall quantity that is neceſſary to ſupply the boiler might be immediately taken from the cold ciſtern, without ſenſibly diminiſhing the production of ſteam; for the quantity of heat neceſſary for raiſing the ſenſible heat of cold water to that of the boiling temperature is ſmall, when compared with the quantity of heat that muſt be combined with it, in order to convert it into ſteam. The heat expended in boiling off a cubic foot of water, is as much as would bring ſix cubic feet to a boiling heat from the temperature of 55°; and little difference can be obſerved in the performance of ſuch engines as are fed with hot water, and thoſe which have their boilers ſupplied from a brook. The hot water has, however, the advantage of being free from air; and when an engine muſt derive all its ſupplies from pit-water, the water from the eduction-pipe is far preferable to that from the top of the cylinder, becauſe it has been in a meaſure boiled and diſtilled.

The interior ſurface of the cylinder requires to be bored with great exactneſs; and it muſt have a ſufficient thickneſs of metal to reſiſt the preſſure of the atmoſphere, without bending or altering its figure. The piſton is made of caſt-iron, as nearly as poſſible to fit the inſide of the cylinder, and has all round it, within two inches of the edge, a circular ledge or rim projecting upwards from it, which is both to ſtrengthen the piſton, and alſo to leave a ſpace round between it and the ſide of the cylinder, to receive the packing or wadding which keeps the piſton tight. Mr. Smeaton, who made the beſt engines on Newcomen's plan, cauſed the lower ſurface of the piſton to be always planked with elm or beech, about 2½ inches thick. The planking conſiſted of two broad planks, croſſing each other at right angles, and halved into each other at the interſection, ſo as to come to an equal thickneſs: the remaining parts or ſectors between the arms of this croſs were filled up with pieces of the ſame plank, well tongued and fitted together, and bolted faſt to the caſt-iron of the piſton with one or two iron rings, let in flat under the lower ſurface to make it ſtrong: the whole was ſurrounded with an iron hoop, a quarter of an inch leſs than the internal diameter of the cylinder. In this caſe, the caſt-iron piſton was made leſs than the wood which formed the bottom of the groove, to receive the wadding, whilſt the edge of the caſt-iron formed the upright ſide thereof. The wooden bottom was ſcrewed to the iron with a double thickneſs of flannel and tar, to exclude the air between the iron and the wood. By this means the piſton was leſs liable to conduct heat; and the wood, being placed with the grain radiating in all directions from the centre, was not liable to expand by the wet. The ſhank of the piſton is made with two prongs, to unite it firmly to the piſton; and if the engine is large, it has four prongs, to balance it equally; and the ſhank muſt alſo have two or four chains upon the arch-head. But the chains, when more than one is uſed, muſt be united in pairs to the ends of a ſhort horizontal link; and from the middle of this the ſhank muſt be ſuſpended, by which means the ſtrain will be equally divided between the two chains. When there are four chains, they muſt be divided into two pairs, with horizontal links, as above; and the middle parts of theſe two links muſt be united to the ends of a longer horizontal link, from the middle of which the ſhank of the piſton is hung: and in this way all the four chains will bear equally.

The upper ends of the chains are jointed to the ends of ſtrong iron bars, ſupported on the ends of the arch-heads; and at the other ends bolted to the top of the beam, by which means they brace the arch-head.

The original method of making the great working beam was to employ a large tree, and to place the gudgeon or fulcrum under the middle of it, with proper bands to faſten it. The framed beam, repreſented in the view, was made by Mr. Smeaton: the two middle pieces are formed of whole balks, 12 inches ſquare, put together with the gudgeon between them, which is five inches thick, and notched into the beams, to make it keep its place: the ends of the beams are then ſprung together, and bolted faſt. This being done, another pair of timbers is applied on the outſide of the two former, and others on the outſide of theſe, for the largeſt engines, making ten balks in the whole. When all theſe are firmly united, ſeveral mortiſes are cut through between the joints, as ſhewn by the ſmall ſquare marks in the figure; and into theſe, hard oak wedges are driven, ſo that they will be half in each beam, and prevent them from ſlipping or ſliding upon each other in the leaſt; and, in this caſe, the beams act as ties by the longitudinal ſtrength rather than their flexibility. The great beams which ſuſpend the cylinder, and extend acroſs the houſe, are compounded of ſeveral pieces, in the ſame manner; and the cylinder has a projecting flanch from the middle of it, to bolt it down to the beams.

The pump-rods or ſpears, K, are made of wood, with iron ſtraps let in and bolted to them at each end, to join them together: they are made of fir, which is very good wood, as it will bear a great ſtrain endways, if the iron ſtraps are well fitted, and can be obtained in very long pieces. When a mine is of a conſiderable depth, the pumps cannot be made to lift the whole at once; but the pit muſt be divided into two, three, or four lifts, and as many different pumps employed; each lifting the water into a ciſtern, for the ſupply of that which is above it. Fifty yards are as much as is proper for each lift, but in ſome very deep mines they are obliged to make them more. It is very difficult, in theſe caſes, to make all the pipes ſufficiently ſtrong to bear the preſſure of the water, particularly the ſhock which takes

place when the whole column of water falls upon the valves in ſhutting: the blow which they then make is like the ſtroke of a forge-hammer, and ſoon beats every thing to pieces. The only effectual remedy is the addition of an air-veſſel at the ſide of the pump; but in general the miner makes a hole in the ſuction-pipe of the pump, juſt below the clack, and fixes in a cock, with a ſmall valve opening outwards: through this they admit a certain quantity of air every time the pump draws, and this air, mixing with the water in the barrel, condenſes, when the valves ſhut ſuddenly, and by its elaſticity eaſes the violence of the ſhock. When the mine is pumped almoſt dry, the engine will draw a little air at every ſtroke, at the bottom of the pipes; and this anſwers the ſame purpoſe. See a deſcription of a new pump for mining in our article PUMP.

Rules for determining the Proportions of Atmoſpheric Engines.—Mr. Newcomen brought forward his engine at a time when almoſt all the valuable mines in England were coming to a ſtand for want of more powerful or cheaper machines than were then known; and in conſequence, in a few years his invention was put in practice at almoſt all the mines then exiſting; and new ones were opened in ſituations where it would have been impoſſible to have done it before. The firſt perfect engine which they erected at Griff, in Warwickſhire, had only a 22-inch cylinder, and it was many years before any were made ſo large as 36: thoſe which we now call ſmall engines, were ſo much more powerful than any former means of draining water, that they were amply ſufficient, until the mines, by growing deeper, required more power. The moſt obvious means of increaſing the force was to change the cylinder for a larger one, and this was moſt frequently done one or more times; and then, when the beam and other parts would bear no greater ſtrain, a new and larger engine was erected. In this manner they proceeded for many years, until, by gradual increaſe, the cylinders for common uſe had reached the enormous powers of 50, 60, and 72 inches diameter.

When it became impracticable to extend them much larger, engineers began to conſider the means of improving their performance without increaſing their dimenſions: alſo, the conſumption of fuel in theſe large engines was ſo ſerious an expence, as to balance the profits of many mines.

At firſt the fuel was not conſidered as an object, becauſe the ſteam-engine, on the whole, was found ſo much cheaper than any other means of draining water. The beſt engineers were thoſe who made engines which would fulfil the taſk aſſigned to them, and, in compariſon to their dimenſions and expence of erection, would draw the moſt water, and be the moſt certain in the continuance of their operation. We have no accounts of the quantity of fuel conſumed by any of thoſe early engines, in proportion to the water which they raiſed to any given height; but the rules by which they apportioned their cylinders to the work to be performed have been preſerved.

Deſaguliers tells us, that Mr. Newcomen's way of finding the power of his engine, was to ſquare the diameter of the cylinder in inches, and cut off the laſt figure, and then call it long hundred weights; and writing a cypher on the right hand, he called the number on that ſide odd pounds: this he reckoned tolerably exact at a mean, or rather when the barometer was at 30 inches, and the air heavy. The effect of cutting off the laſt figure from the ſquare of the diameter, is to divide the number of ſuperficial circular inches on the piſton's ſurface into portions of 10 circular inches each; and as the preſſure on each of theſe portions is eſtimated at a long hundred weight, or 120 lbs., the preſſure will be $120 \div 10 = 12$ lbs. *per* circular inch, or 15.3 lbs. *per* ſquare inch: this, however, muſt be conſidered as the full preſſure of the atmoſphere, if the vacuum was perfect. But to compenſate for imperfection, Newcomen allowed between one-third and one-fourth part, and alſo for what is loſt in the friction of the ſeveral parts, and for accidents. If, inſtead of the long hundred of 120 lbs., Newcomen had taken the common hundred of 112 lbs., he would have had $112 \div 10 = 11.2$ lbs. *per* circular inch, or $14\frac{1}{4}$ lbs. *per* ſquare inch, which is ſtill nearer the medium preſſure of the atmoſphere.

Deſaguliers ſays this rule will agree pretty well with the work at Griff engine, there being lifted at every ſtroke between two-thirds and three-fourths of the weight of the atmoſpherical column preſſing on the piſton; *i. e.* between 10 and $11\frac{1}{4}$ lbs. on each ſquare inch. To give the eſtimation in round numbers, the diameter of the cylinder of Griff engine will be = 22 inches; this ſquared is 484; cut off the laſt figure, and we have 48 cwt. 40 lbs. for the preſſure of the atmoſphere. The column of water in the pumps weighs about $27\frac{1}{2}$ cwt., to which adding the weight of 73 yards of iron rods, equal about 9 cwt., the weight lifted at the end of the beam would be $36\frac{1}{2}$ cwt., from which we muſt ſubtract about 4 cwt. for the piſton, and the other weight at that end of the beam, reducing the load to $32\frac{1}{2}$ cwt.; ſo that the weight of the atmoſphere being 48 cwt. 40 lbs. raiſes a weight of $32\frac{1}{2}$ cwt. with a velocity of ſix feet in two ſeconds, conſidering only the deſcending ſtroke of the piſton. This requires an effective preſſure on the piſton of nearly 11 lbs. *per* ſquare inch, including friction and counter-weight; but to balance the weight of the water in the pump, demands a preſſure of only 8 lbs. *per* ſquare inch of the piſton.

In calculating the powers of the ſteam-engine, it has been a common miſtake with engineers to take into the account no other circumſtances than the diameter of the cylinder, and the perpendicular height and diameter of the pumps; from which they calculate only what burthen is laid upon each ſquare inch of the cylinder or piſton area, ſuppoſing the piſton to be at reſt, but without paying any regard to the velocity of the engine's motions under ſuch burthen, or the number of ſtrokes *per* minute. Without taking theſe particulars into the account, it is impoſſible to calculate the quantity of water raiſed to a given height, which is the only means of obtaining the exact power or acting force of an engine: it would be like attempting to meaſure the contents of a ſolid body by only two dimenſions. Steam-engines have at different times been calculated to carry a load varying from 5 lbs. to upwards of 10 lbs. to the ſquare inch; but when working with the light preſſure of 5 lbs. to the inch, they are expected to go with double the velocity; that is, the piſton to move through double the ſpace in the ſame time that it would with a preſſure of 10 lbs. In this caſe the ſame quantity of water would be raiſed to a given height in the ſame ſpace of time. In the ſteam-engine, as well as in other machines, there is a maximum, which cannot be exceeded without applying ſome new principle; and though by bad workmanſhip an engine may fall ſhort of what it ſhould do, the beſt workmanſhip can only produce a certain effect.

In eſtimating the power or effect of engines in this manner by the pounds *per* inch in the area of the piſton, it muſt be conſidered as the clear product of the engine in the column of water it will raiſe, abſtracted of all deductions for friction, counter-weight, &c. For, by attending to the different lifts of pumps in the engine-ſhaft of a coal or a copper mine, we find that we muſt, beſide the altitudes and the diameters, take into the account the friction of the buckets, and of the water on the ſides of the pumps; the

opening of ſtrong double-leathered valves, together with the ſtones and gravel that enter at the foot of the pump; the inertia of the pump-rods, the chains, the maſſive lever placed between the cylinder and the pumps, all to be overcome by the preſſure on the piſton, in addition to the 7 or 8 lbs. *per* ſquare inch. Theſe additions to the power required for the mere raiſing of the water are ſo conſiderable, as to be at leaſt equal to half what is required for the work performed: this will raiſe the real acting preſſure of the atmoſphere to 10½ or 12lbs. *per* ſquare inch. When this is the caſe, the vapour which remains in the cylinder muſt be equal in preſſure to 4½ or 3 lbs. *per* ſquare inch; and this, by our firſt table of expanſion, will indicate a temperature of from 155° to 142° of Fahrenheit.

In general, the water in the hot-well indicates a lower temperature than this; but although we have but little information concerning the ſtate of the vacuum in the atmoſpheric engines, when working in their uſual ſtate, it muſt be conſiderably more perfect than has been ſuggeſted by the idea of a preſſure of 8 lbs. *per* inch: for an engine carrying a load of 7½ lbs. on the ſquare inch of the piſton, together with the friction and inertia, even in large engines, cannot be leſs than 11½ lbs. on the inch. Mr. Hornblower informs us that he tried the vacuum of ſeveral engines in the county of Cornwall; and in one, which was reckoned the leaſt, the vacuum in the cylinder brought the barometer-gauge to 23, and ſometimes 24 inches, inſtead of 30 inches, at which it would have ſtood if the vacuum was perfect. If we take the extreme of theſe obſervations, it will be 11.6 lbs. on each ſquare inch.

Mr. Henry Beighton ſeems to have been the firſt who reduced the ſteam-engine to any degree of certainty in its operations, and laid down the rules for calculating its powers. Beighton was a mathematician as well as an engineer, and conducted the Ladies Diary from 1714 to 1744. For ſeveral years he lived at Griff, and had conſtant opportunities of trying experiments on engines.

We have before noticed his invention of the working-gear, or mechaniſm, by which the regulator and ſteam-cock are alternately opened and ſhut. In 1717, Mr. Beighton publiſhed the following table of the neceſſary proportions of the cylinders of engines to the pumps, when drawing water at different depths, from 15 to 100 yards, in different quantities, from 48 to 480 hogſheads *per* hour.

Pumps.							Cylinders. Diameters of the Cylinders. The Depth from which Water is to be drawn. Yards.												
Diameter of the Bore	Will hold in a Yard.	Will draw by a Six-feet Stroke.	Weight in one Yard.	At ſixteen Strokes in a Minute.	Sixty-three Gallons to a Hogſhead.	In one Hour.	15	20	25	30	35	40	45	50	60	70	80	90	100
In.	Gallons	Gallons.	Lbs.	Gallons.	H. G.	H. G	In.	In.	In.	In	In.	In.	In.	In.	In.	In.	In.	In.	In.
12	14.4	28.8	146.	462.	7.21	440.	18½	21¾	24	26½	28½	30½	32½	34¼	37¼	40			
11	12.13	24.	123.5	338.	6.20	369.33	17	19¾	22	24¾	26¼	28	29¾	31¼	34¼	37	39½		
10	10.02	20.04	102.	320.	5.5	304.48	15½	18	20	22	23¾	25¼	27	28¾	31¼	33¾	36	38¼	40
9	8.12	16.2	82.7	259.8	4.7	247.7	14	16¼	18	20	21½	23	24¼	25	28	30½	33	35	36½
8½	7.26	14.5	73.9	232.3	3.43	221.15	13½	15¼	17¼	19	20¼	21¾	23	24	26¼	28½	31	32½	35¼
8	6.41	12.8	65.3	205.2	3.16	195.22	12½	14½	16½	18½	19	20½	21½	23	25	27	29	30½	32½
7¾	6.01	12.2	61.2	192.3	3.2	182.13	12	14	15½	17½	18¾	19¾	21	22	24¼	26	28	29½	31½
7½	5.66	11.3	57.6	181.1	2.55	172.30	11	13¾	15	16½	18	19	20	21¼	23¼	25	27	28½	30¼
7	4.91	9.8	50.0	157.1	2.31	149.40	10¾	13	14	15½	16½	18¾	19	20½	22	24	25½	27	28½
6½	4.23	8.4	43.0	135.3	2.9	128.54	10	12	13	14	15½	16¼	18	19	20	22	23	24½	26¼
6	3.61	7.2	36.7	115.5	1.52	110.1	9½	11	12	13	14	15½	16	17	19	20½	22	23	24½
5½	3.13	6.2	31.8	99.2	1.36	94.30		10	11	12	13	14	15	15¾	17	19	20	21	22¼
5	2.51	5.0	25.5	80.3	1.7	66.61			10	11	11¾	13	13¾	14	15½	16¾	18½	19¼	20¼
4½	2.02	2.4	20.5	64.6	1.1	60.60				10	11	11¾	12	13½	14	15	16	17	18¼
4	1.6	3.2	16.2	51.2	0.51	48.51					9	10	11	11½	12	13½	14	15	16

This table is formed on the foundation of the ale-gallon, (containing 282 cubic inches,) which, when filled with pure running water, weighs 10 lbs. 3 oz. avoirdupois; and a ſuperficial inch, on a vacuum, takes in about 14 lbs. 13 oz. of the atmoſphere, when the mercury ſtands at a medium in the barometer.

But allowing for ſeveral frictions, and to give a conſiderable velocity to the engine, experience has taught us to allow but little more than 8 lbs. to an inch in the cylinder's baſe, that it may make about 16 ſtrokes in a minute, at about ſix feet each.

An Example for the Uſe of this Table.—Suppoſe it was required to draw 150 hogſheads *per* hour, at 90 yards deep; in the ſeventh column, I ſeek the neareſt number, *viz.* 149 hogſheads, and againſt it, in the firſt column, I find a pump of ſeven-inch bore; then under 90, the depth on the right hand in the ſame line, I have 27 inches, the diameter of the cylinder fit for that purpoſe, and ſo for any other. Henry Beighton.

This eſtimation of 8 lbs. preſſure for each ſquare inch continued for many years to be the rule with engineers who conſtructed their engines according to this proportion; and if the engines were of a better or worſe conſtruction, they would move with a greater or leſs velocity, becauſe all the exceſs of preſſure which could be obtained above the 8 lbs. was appropriated to overcome the friction and vis inertia of the machine; and alſo to raiſe the counter-weight: if, therefore, this additional quantity was greater or leſs, the engine would move quicker, and raiſe a greater quantity of

water in the same time. Mr. Beighton expected his engine to move 16 strokes *per* minute, of six feet each, or 96 feet of motion *per* minute; but succeeding engineers found them seldom to come up to this, and then began to diminish the burthen to 7 lbs. *per* square inch, and even 6 lbs., in order to obtain a greater velocity of motion.

The celebrated engineer Mr. John Smeaton carried the engine of Newcomen to perhaps as great a degree of perfection as its principle admitted. Having constant occasion to employ large steam-engines in the great works which he executed, he turned his attention to consider the means of improving their effect, and diminishing the consumption of fuel. In calculating the proportions for an engine for the New River Company, in 1767, he considered that the stoppage of the water at every stroke, as well as putting the lever-beam, piston, heavy rods, and chains, from a state of rest into motion, twice at every stroke, was a great loss of power; he therefore determined to work the engine slower, and with larger pumps, and put upon the piston all the load it would bear. To reduce the velocity of the column of water still more, he would place the fulcrum of the beam out of the centre, and make the stroke of the piston nine feet, whilst the pump which lifted 36 feet should work with only a six-feet stroke. This arrangement obliged him to employ a long narrow cylinder, of only 18 inches diameter, and from this he also expected to obtain other advantages; *viz.* that every part of the steam, being nearer the surface of the cylinder, would be more readily condensed; and, in consequence that a less quantity of injection-water would serve the cylinder, which would itself be more heated. Under all these appearances of advantage, he ventured to burden the piston with a pressure of 10.4 lbs. *per* inch. Thus, area of piston (18 inches diameter) 254; weight of the column of water 36 feet in the pumps, 18 inches diameter, 3960 lbs., of which take $\frac{2}{3}$ths for the difference of the length of stroke, and it gives 2640 lbs. for the weight to be lifted by the piston; and dividing 2640 by 254, the area of the piston, gives 10.4 lbs. pressure *per* inch. "Having once seen a common engine struggle under this burthen, I thought myself (says this ingenious engineer) quite secure under those advantages; but how great was my surprize and mortification, to find that, instead of requiring less injection-water than common, although the injection-pump was calculated to afford as much injection-water as usual, in proportion to the area of the cylinder, with a sufficient overplus to answer all imaginable wants, it was unable to support the engine with injection; and that two men were obliged to assist to raise the injection-water quicker by hand, to keep the engine in motion: at the same time that the cylinder was so cold, I could keep my hand upon any part of it, and bear it for a length of time in the hot-well. By good fortune, the engine performed the work it was appointed to do, as to the raising of water; but the coals by no means answered my calculation. The injection-pump being enlarged, the engine was in a state of doing business, and I tried many smaller experiments, but without any good effect, till I altered the fulcrum of the beam so much, as reduced the load upon the piston from $10\frac{1}{2}$ lbs. to $8\frac{1}{4}$ lbs. *per* inch. Under this load, though it shortened the stroke at the pump-end, the engine went so much quicker, as not only to raise more water, but consume less coals, took less injection-water, the cylinder become hot, and the injection-water came out at 180° of Fahrenheit; and the engine in every respect not only did its work better, but went more pleasantly. This at once convinced me that a considerable degree of condensation of the steam took place in entering the cylinder, and that I had lost more this way by the coldness of the cylinder, than I had gained by the increase of load. In short, this single alteration seemed to have unfettered the engine; but in what degree this condensation took place under different circumstances of heat, and where to strike the medium, so as upon the whole to do best, was still unknown to me. But resolving, if possible, to make myself master of the subject, I immediately began to build a small fire-engine at home, that I could easily convert into different shapes for experiments, and which engine was very near ready to set to work in the winter of 1769."

With this experimental engine, which is represented in *Plate* III. *Steam-Engine*, Mr. Smeaton made a multitude of experiments, which he noted down with great care in tables, and from their results deduced rules for the proportions of the parts of his engines: he afterwards erected many engines of the largest dimensions, which fully verified his experiments: the first of these was at Long Benton colliery, in 1774, which had a 52-inch cylinder, and afterwards a 72-inch, for the empress of Russia, at Cronstadt.

Mr. Smeaton's Experimental Engine.—Plate III. contains an elevation of this engine, shewing all its parts at one view; and, after the minute description which we have given of Mr. Newcomen's engine in *Plate* II., it is not necessary to enlarge on the particulars of the present. A, B, are the walls of the building; C groundsills, extending from the wall B, to the wall of the boiler or furnace F; D are strong upright timbers, to support the cross-beam *d*, on which the centre of the beam is sustained; P are the cylinder-beams, framed into the upright D, and the walls A, B; and the cylinder G is hung between them by thick cross-planks *q*, *q*.

M M the great beam, librating on its centre, and formed to arcs of circles at the ends, to which are suspended the chains *h* for the piston, and the chain of the main-pump spear H. It has also attached to it the plug-frame Q, and at the other end an iron rod K, which works the injection or jack-head pump, I, by means of a counter lever *a a*, which brings the rod, *i*, of the pump to a convenient place, near the main-pump O O. The proper distance for the motion of the beam is limited by two iron fidds or pins *b*, *b*, which reach out from each side of the arch-heads, and stop on pieces of wood, supported by the beams S, called the spring-beams. These beams also, which support the upper floor of the house, are let into the walls A, B, at the ends, and rest in the middle on the cross-beam *d*, and are firmly bolted down, as shewn in the drawing.

N is the injection-pipe, 13 the injection-cock, and X the piston water-cock, branching off from the injection-pipe N. L is the injection-cistern, placed in the highest part of the house; *k k* is the pipe from the injection-pump I, by which it is supplied; and T is the waste-pipe, at which the excess of water runs off. The pipe T leads down to the small cistern *z*, which will always be kept full, and the overflow will run down the waste-pipe *l e*, and escape out of doors.

f is the fire-door, and the ash-pit is beneath it: the fire circulates round the boiler, and then passes into the chimney *g*: *x* is a small door at the bottom of the chimney, to clear the soot, and there is also a damper to regulate the draft: *z* is the boiler, and its figure below is shewn by the dotted lines: *v* is a pipe rising from it, which has the safety-valve at the top of it, contained in a box or trough, which carries the steam through the wall at *w*: *n* is the steam-gauge, a small bent glass tube, which contains mercury, and shews the pressure of the steam. The cylinder G, besides the bored part in which the piston works, has a bottom W, screwed on by a flanch at the lower part, and from this bottom part descends the steam-pipe S. The short pipe, 12, joins to the lower end of the injection-pipe N N; and

oppofite to this is a fimilar fhort pipe, for the fnifting-valve. Alfo from the bottom of the cylinder there defcends the fink, or eduction-pipe *m*, which enters the hot-well R, and the end is covered with a valve. S is the wafte-pipe, from which the excefs of hot water in the hot-well is carried off into the well E E.

As the hot-well is placed fo low that the boiler cannot be fupplied from it, a fmall feed-pipe, *p*, proceeds from the lower part of the cylinder, and enters the boiler, having a cock, *p*, to regulate the quantity which fhall pafs through, and a valve to prevent the water being drawn up from the boiler into the cylinder. In the top of the boiler is the regulator-plate, 7, to the under furface of which the regulator is fitted: the handle or lever of the regulator is alfo feen, and the fpanner or rod 5, by which it is alternately moved backwards or forwards by the arms 3 and 4 of the ⅄. When its weight or bob, 3, falls over on either fide of the perpendicular, it is checked by the ftrap 9: 1 and 2 are the arms or handles by which the ⅄ is moved when the pins in the plug-beam, Q, act upon them, and 6 is a weight to balance the weight of the handles.

10, 11 is the F, or lever of the injection-cock; it is connected with the handle of the cock, 13, by a fork, which cannot be feen; and the end, 11, is loaded with a fufficient weight to caufe its defcent, and open the cock, except when it is elevated, by preffing down the end 10; and when it is held up by the hook 12, the cock will then be fhut; but when the plug-frame rifes to its higheft, it draws the wire 14, and lifts the catch 12, fo as to let fall the weight 11, and opens the cock in an inftant.

The action of this engine is apparent after the explanation which we have given of the former engine, and it is only neceffary to explain a fmall machine which is contained in the ciftern V, called the cataract: it was very commonly ufed in the engines for the mines in Cornwall, to regulate the motion of the engine to any given number *per* minute, fo that the defired quantity of water could be drawn, without wafting fteam in drawing more.

The cataract is nothing more than a fmall tumbling-bob, moving on a centre within the box V, in the fame manner as the ⅄; but inftead of the weight or bob at the top, it has a fmall box or cup, which is filled with water by a fmall ftream dropping continually from the fmall ciftern *z*, through a cock. The lever, on which the cup is fixed, has a fecond lever and counter-weight applied to it, which makes it always affume the vertical pofition, or nearly fo, except when the cup is full, and then it is of fufficient weight to make the cataract-tumbler fall over, and in that pofition the cup inclines fo much, that it difcharges its contents, and the counter-weight caufes its immediate return. The cataract, when it falls over, ftrikes a piece which is connected with a wire 15, and this by a lever, 16, and the fecond wire, 17, draws up the catch 12.

When the engine works with the cataract, the wire 14, before mentioned, is detached; and in this ftate we will fuppofe the regulator open, the injection-cock fhut, and the pifton to have juft arrived at the top of the cylinder. A pin in the plug-beam, Q, feizes the handle 1, overthrows the tumbling-bob, 3, of the ⅄ towards the cylinder, and the prong, 3, of the fork of the ⅄ draws the rod 5, and fhuts the regulator. In this fituation the engine will remain, until the ftream, which flows from the ciftern *z*, through the cock, fills the cup at the top of the cataract, and caufes it to fall over; it then ftrikes fuddenly on the piece of the wire 15, and by the lever 16, and wire 17, it raifes the hook-catch 12. This lets fall the weight 11, and opens the injection-cock, to throw a jet in the cylinder, which condenfes the fteam therein, making the pifton to defcend; and when it arrives at the bottom, the pin in the plug Q depreffes 10, which fhuts the injection, and then, by depreffing 2, overthrows the tumbling-bob, and opens the regulator. This admits fteam again into the cylinder, and the counter-weight makes the pifton return. The cataract returned the inftant that its cup inclined fo much as to throw out its water, and the cup then began to fill again; but it will not again act, or difcharge the injection-cock, until it is quite filled; and the injection-cock will not open till this happens; fo that the engine waits at the top of the ftroke till the cataract is ready: and this time of waiting can be regulated, by diminifhing or increafing the fteam which drops down the cock, fo as to draw up exactly as much water as drains into the mine.

In 1765, Mr. Smeaton made a portable fteam-engine for draining foundations, or other temporary works. It had a pulley or wheel, to receive the chain which communicated motion from the pifton to the pump-rod, inftead of a beam; and the whole machine being fupported in one frame of wood, it had no connection with the building in which it was placed, or it could work all together in the open air. The frame was fhaped like the letter A, and the vertex fupported the pivots of the wheel, whilft the cylinder and pump were bolted down to the groundfills, on which the A was erected. The engine in its action was the fame as others; the boiler required no fetting in brick-work, but was in the fhape of a large tea-kettle, and the fire-place was in the centre of it, furrounded on all fides by the water. On one fide was an opening for the fire-door, and a large tube or pipe led through the water to a hollow fphere of caft-iron, in which the fire was made, upon a grate; and from the grate another large tube or afh-pit defcended perpendicularly through the bottom of the boiler, and was open below to fupply air to the fire; alfo oppofite the fire-door was a third large tube or chimney, leading from the fphere through the fide of the boiler, and it then turned up in the manner of the fpout of a tea-kettle, to carry off the fmoke into a tall chimney of brick or of iron-plate.

From Mr. Smeaton's manufcript papers (now in poffeffion of fir Jofeph Banks) we gain much practical as well as philofophical information on the atmofpheric engines; and as thefe engines are ftill ufed very extenfively at coal-mines, we think the publication of the particulars will be of fervice.

Mr. Smeaton's experiments with his experimental engine were very numerous, and fo diverfified, as to afford all the information which can be defired upon Newcomen's engine. It would exceed our limits to tranfcribe many of thefe experiments; but we think it will be ferviceable to give the table of proportions, which he fettled from the refults of all his experiments, and after which table, between the years 1774 and 1782, he erected no lefs than eight firft rate engines, with cylinders of five and fix feet diameters, and many others of fmaller dimenfions. A full defcription, with drawings, of one of thefe engines, is given in the publication of Mr. Smeaton's Reports, 3 vols. 4to. London, 1811.

Mr. Smeaton's Table for the Proportions of the Parts of Newcomen's Engines, deduced from actual Experiments.

Cylinders.			Strokes.			Journey *per* Minute.	Boilers.			Diameter of Steam-Pipe.	Square Hole for Jet of Injection.	Injection-Water *per* Stroke.		Boiler's Feed *per* Stroke.	Coals *per* Hour.	Pumpage.	Great Product *per* Minute.	Effect *per* Minute of one Bushel *per* Hour.
Diameter.	Square of Diameter.	Area in Square Inches.	No.	Length.			Centre-Diameter.		Fire-Surface.			In Ale-Gallons.	Cyl. Inch Ft.					
Inches.	Cir. In.	Sq. In.		Ft.	In.	Feet.	Ft.	In.	Sq. Ft.	Inches.	Inches.			Cub. In.	Bushels.	Cyl. In. Ft.		
12	144	113	16½	4	0	66.	6	0	37½	2.50	·33	·6	18	12.7	·74	2.592	·171.072	231 M.
14	196	153	16¼	4	2	67.71	6	6	44	2.78	·375	·76	23	15·9	·91	3·528	·238.881	263
16	256	201	16	4	4	69.3	7	0	51½	3.06	·42	·93	28	19·7	1.11	4.608	·319.488	288
18	324	254	15¾	4	6	70.88	7	6	58½	3.35	·47	1.13	34	23 9	1.33	5.832	·413.372	311
20	400	314	15½	4	8	72.3	8	0	66½	3.64	·51	1.36	41	28.5	1.56	7.200	·520.800	334
22	484	380	15¼	4	10	73.71	8	6	75½	3.93	·56	1.6	48	33.6	1.81	8.712	·642.162	355
24	576	452	15	5	0	75·	9	0	84	4.22	.60	1.86	56	39.3	2.08	10.368	·777.600	374
26	676	531	14¾	5	2	76.21	9	6	94	4.52	.645	2.16	65	45.3	2.36	12.168	·927.323	393
28	784	615	14½	5	4	77.3	10	0	104	4.82	.69	2.48	74½	52.	2.66	14.112	1.091.328	410
30	900	706	14¼	5	6	78.36	10	6	115	5.12	·735	2.82	84½	59.1	2.97	16.200	1.269.432	427
32	1024	814	14	5	8	79.8	11	0	126	5.43	·78	3.18	95½	66.8	3.30	18.432	1.462.272	443
34	1156	907	13¾	5	10	80.21	11	6	138	5.74	.825	3.56	107	75·	3.64	20.808	1.669.010	459
36	1296	1018	13½	6	0	81.	12	0	150	6.05	.87	4·	120	84·	4.00	23.328	1.889.568	472
38	1444	1134	13¼	6	2	81.71	12	6	163	6.37	·91	4.46	134	93.4	4.37	25.992	2.123.806	486
40	1600	1256	13	6	4	82.3	13	0	176	6.69	·95	4 95	148½	103.7	4.76	28.800	2.371.200	498
42	1764	1385	12¾	6	6	82.88	13	6	190	7.01	·99	5.46	164	114.6	5.16	31.752	2.631.606	510
44	1936	1520	12½	6	8	83.3	14	0	204	7.34	1.03	6.03	181	126.5	5.58	34.848	2.904.000	520
46	2116	1662	12¼	6	10	83.71	14	6	219	7.67	1.07	6.63	199	139·	6.01	38.088	3.188.346	531
48	2304	1809	12	7	0	84.3	15	0	234	8.	1.11	7.26	218	152.5	6.46	41.472	3.483.648	539
50	2500	1963	11¾	7	2	84.21	11	0	252	8.33	1.15	7.96	239	166.9	6.92	45.000	3.789.450	548
52	2704	2123	11½	7	4	84.3	11	6	276	8.66	1.19	8.7	261	182.3	7.40	48.672	4.104.672	555
54	2916	2290	11¼	7	6	84.36	12	0	300	9.	1.225	9.48	284½	198.7	7.89	52.488	4.427.888	561
56	3136	2463	11	7	8	84.	12	0	326	9.33	1.26	10.3	310	216.4	8.40	56.448	4.760.448	567
58	3364	2642	10¾	7	10	84.21	12	0	354	9.66	1.295	11.22	336½	235.1	8.92	60.552	5.099.084	572
60	3600	2827	10½	8	0	84.	12	0	384	10.	1.33	12.18	365½	255.3	9.46	64.800	5.443.200	575
62	3844	3019	10¼	8	2	83.71	12	0	402	10.33	1.36	13.2	396	276.7	10.01	69.192	5.792.062	579
64	4096	3216	10	8	4	83.3	12	0	426	10.66	1.39	14.3	429	299.8	10.58	73.728	6.144.000	581
66	4356	3421	9¾	8	6	82.88	12	0	450	11.	1.425	15.46	464	324.3	11.16	78.408	6.498 455	581
68	4624	3631	9½	8	8	82.3	12	0	476	11.33	1.45	16.73	502	350.7	11.76	83 232	6.852.768	583
70	4900	3848	9¼	8	10	81.71	12	0	502	11.65	1.475	18.08	542½	378.9	12.37	88.200	7.206.822	583
72	5184	4071	9	9	0	81.	12	0	530	12.	1.50	19.53	586	409.3	13.00	93.312	7.558.272	581

The Surface in the Flues is taken at Half.

These have Two Boilers.

The different columns of this table explain themſelves, except the great product *per* minute. This is the effect of the engine expreſſed in a convenient manner, to ſeparate it from all conſiderations of the diameter or lift of the pumps, or of the number of ſtrokes which the engine makes in a minute; being the multiple of all theſe, and is thus obtained. Multiply the ſquare of the diameter of the cylinder in inches, by the preſſure on each ſquare inch of the piſton, not expreſſed in pounds weight, but in the height of a column of water in feet; and this again is multiplied by the velocity of the motion of the piſton *per* minute. For example, a 26-inch cylinder: ſquare of diameter, (676) × 18 feet, the preſſure *per* ſquare inch in feet of water, = 12168 × 76.21 feet, the journey *per* minute, = 927323, the great product *per* minute, as *per* table. The table is calculated upon the ſuppoſition that the preſſure upon each ſquare inch of the piſton is 8 lbs. avoirdupois, or 18 feet column of water.

The laſt column, or effect *per* minute of one buſhel *per* hour, is a comparative view of the effect of different-ſized engines, ſhewing the advantages of large engines in reſpect to ſmall, in the quantity of work they will effect in proportion to the coals they conſume.

To find the number of buſhels of coals which any of the engines will conſume *per* hour, calculate the internal ſurface of the cylinder in ſquare inches, and add to it three times the ſquare of the diameter, to allow for the piſton bottom, cylinder bottom, and the ſurface of the pipes which are within the cylinder. Next calculate the ſolid content of the cylinder in cubic inches, and find the proportion between the ſuperficial and the ſolid meaſure of the cylinder: according to the number of this proportion, find a number in the following table for a diviſor.

...portio of ...e Surface of Cylinder to ...s Capacity ...ſquare and ...bic Inches.	Effect of one Buſhel *per* Hour.	Differences.
	98	
2	188	90
3	273	85
4	349	76
5	414	65
6	468	54
7	512	44
8	545	33
9	567	
10	578	
11	578	
12	572	

Laſtly, cut off three places of figures from the great product *per* minute, and dividing by the diviſor, the quotient will be the effect of one buſhel *per* minute.

For example, a 72-inch cylinder: its circumference will be 226.3, which, multiplied by 135 inches, the length, gives 30550 ſquare inches; and adding thereto 15552, which is three times the ſquare of the diameter, we have 46102 ſuperficial inches; and the content of the cylinder is 549652 cubic inches, which is 11.9 times the number of the ſuperficial inches. By ſeeking in the laſt table for 11.9 or 12, we find the number 572 for the diviſor of the great product, after cutting off its three laſt figures, *viz.* 7558 ÷ 572 = 13 buſhels *per* hour.

By this way of finding the proportion between the ſurface and the content of the cylinder, an allowance is made for the loſs of ſteam which takes place from condenſation, when it enters into the cylinder at every ſtroke, after it has been cooled by the injection thrown into it.

The quantity is very conſiderable, and forms the greateſt objection to this form of the ſteam-engine. An attentive obſervation to the action of an engine will ſhew that there is a waſte, but not the quantity in which it takes place. The moment the regulator is opened, when the piſton is at the bottom of the ſtroke, the ſteam may be perceived to iſſue from the ſnifting-valve with a ſtrong puff, becauſe the ſteam is more elaſtic than air by one or two pounds *per* ſquare inch; but as the piſton riſes, this ſteam diminiſhes, and ſoon ceaſes, and no more ſteam will iſſue during the whole riſe of the piſton.

To aſcertain the quantity of this loſs by condenſation, it becomes firſt neceſſary to know to what degree water is expanded, when converted into ſteam, at the preſſure of the atmoſphere; and compare this with the degree of expanſion which it requires to convert the water, which the boiler conſumes in a given time, into ſuch a quantity of ſteam as will fill the cylinder the requiſite number of times in the ſame period.

Mr. Beighton made an experiment at Griff engine, in Warwickſhire, on the degree of rarefaction of water when converted into ſteam, but without determining the temperature. The preſſure of the ſteam was juſt one pound upon the ſquare inch, as he determined by the ſteelyard of the ſafety-valve; and by our ſecond table, we find this to denote a temperature of about 216°. The cylinder of the engine contained 113 gallons of ſteam at every ſtroke, which, at 16 ſtrokes *per* minute, is equal to 1808 ale-gallons, or 1808 × 8 = 14464 pints of ſteam *per* minute. He found that the neceſſary ſupply of freſh water for the boiler, under theſe circumſtances, was about five pints *per* minute, to keep the ſurface of the water at a conſtant level; therefore, the relative bulks of the ſteam of one pound *per* inch preſſure, and the water from which it was produced, were as 5 to 14464, or as 1 to 2893 nearly. By an unaccountable miſtake, Deſaguliers, who relates the above experiment, deduces from the ſame data, that the expanſion is 13388, a number which has been frequently quoted by other writers. Mr. Beighton's experiment cannot be admitted as concluſive, becauſe the cylinder being cooled by the condenſing water at every ſtroke, the ſteam would be condenſed, and loſe much of its bulk in entering into the cold cylinder. But without making any allowance for that loſs, Mr. Beighton's experiment makes a greater degree of expanſion than has been found by others; and we ſhould not have mentioned this experiment at all, had it not been ſo frequently quoted after Deſaguliers with his enormous error, even by Belidor, Prony, and other foreign writers.

Mr. Smeaton made ſome experiments by weighing a Florence flaſk of four inches diameter, firſt when it was perfectly dry and empty, and afterwards when it was full of water; then pouring out all the water, except a ſmall quantity, he put the globe on the fire, and made it boil ſtrongly, till the laſt drop of water diſappeared, and at that inſtant he ſtopped up the mouth to retain the ſteam which was within it. The flaſk being now weighed, gave the difference of weight between the flaſk filled with water and with ſteam of an elaſtic force equal to that of atmoſpheric air; and deducting the weight of the empty flaſk from each of theſe

experiments,

Mr. Smeaton's Table for the Proportions of the Parts of Newcomen's Engines, deduced from actual Experiments.

Cylinders.			Strokes.			Journey per Minute.	Boilers.			Diameter of Steam-Pipe.	Square Hole for Jet of Injection.	Injection-Water per Stroke.		Boiler's Feed per Stroke.	Coals per Hour.	Pumpage.	Great Product per Minute.	Effect per Minute of one Bushel per Hour.
Diameter.	Square of Diameter.	Area in Square Inches.	No.	Length.			Centre-Diameter.		Fire-Surface.			In Ale-Gallons.	Cyl. Inch Ft.					
Inches.	Cir. In.	Sq. In.		Ft.	In.	Feet.	Ft.	In.	Sq. Ft.	Inches.	Inches.			Cub. In.	Bushels.	Cyl. In. Ft.		
12	144	113	16½	4	0	66.	6	0	37½	2.50	·33	·6	18	12.7	·74	2.592	.171.072	231 M.
14	196	153	16¼	4	2	67.71	6	6	44	2.78	·375	.76	23	15.9	·91	3.528	.238.881	263
16	256	201	16	4	4	69.3	7	0	51½	3.06	·42	·93	28	19.7	1.11	4.608	·319.488	288
18	324	254	15¾	4	6	70.88	7	6	58½	3.35	·47	1.13	34	23 9	1.33	5.832	·413.372	311
20	400	314	15½	4	8	72.3	8	0	66½	3.64	·51	1.36	41	28.5	1.56	7.200	.520.800	334
22	484	380	15¼	4	10	73.71	8	6	75½	3.93	·56	1.6	48	33.6	1.81	8.712	.642.162	355
24	576	452	15	5	0	75·	9	0	84	4.22	.60	1.86	56	39.3	2.08	10.368	·777.600	374
26	676	531	14¾	5	2	76.21	9	6	94	4.52	.645	2.16	65	45.3	2.36	12.168	·927.323	393
28	784	615	14½	5	4	77.3	10	0	104	4.82	.69	2.48	74½	52.	2.66	14.112	1.091.528	410
30	900	706	14¼	5	6	78.36	10	6	115	5.12	·735	2.82	84½	59.1	2.97	16.200	1.269.432	427
32	1024	814	14	5	8	79.8	11	0	126	5.43	·78	3.18	95½	66.8	3.30	18.432	1.462.272	443
34	1156	907	13¾	5	10	80.21	11	6	138	5.74	.825	3.56	107	75·	3.64	20.808	1.669.010	459
36	1296	1018	13½	6	0	81.	12	0	150	6.05	.87	4·	120	84.	4.00	23.328	1.889.568	472
38	1444	1134	13¼	6	2	81.71	12	6	163	6.37	·91	4.46	134	93.4	4.37	25.992	2.123.806	486
40	1600	1256	13	6	4	82.3	13	0	176	6.69	·95	4 95	148½	103.7	4.76	28.800	2.371.200	498
42	1764	1385	12¾	6	6	92.88	13	6	190	7.01	·99	5.46	164	114.6	5.16	31.752	2.631.606	510
44	1936	1520	12½	6	8	83.3	14	0	204	7.34	1.03	6.03	181	126.5	5.58	34.848	2.904.000	520
46	2116	1662	12¼	6	10	83.71	14	6	219	7.67	1.07	6.63	199	139	6.01	38.088	3.188.346	531
48	2304	1809	12	7	0	84.3	15	0	234	8.	1.11	7.26	218	152.5	6.46	41.472	3.483.648	539
50	2500	1963	11¾	7	2	84.21	11	0	252	8.33	1.15	7 96	239	166.9	6.92	45.000	3.789.450	548
52	2704	2123	11½	7	4	84.3	11	6	276	8.66	1.19	8.7	261	182.3	7.40	48.672	4.104.672	555
54	2916	2290	11¼	7	6	84.36	12	0	300	9·	1.225	9.48	284½	198.7	7.89	52.488	4.427.888	561
56	3136	2463	11	7	8	84.	12	0	326	9.33	1.26	10.3	310	216.4	8.40	56.448	4.760.448	567
58	3364	2642	10¾	7	10	84.21	12	0	354	9.66	1.295	11.22	336½	235.1	8.92	60.552	5.099.084	572
60	3600	2827	10½	8	0	84.	12	0	384	10.	1.33	12.18	365½	255.3	9.46	64.800	5.443.200	575
62	3844	3019	10¼	8	2	83.71	12	0	402	10.33	1.36	13.2	396	276.7	10.01	69.192	5.792.062	579
64	4096	3216	10	8	4	83.3	12	0	426	10.66	1.39	14.3	429	299.8	10.58	73.728	6.144.000	581
66	4356	3421	9¾	8	6	82.88	12	0	450	11.	1.425	15.46	464	324.3	11.16	78.408	6.498 455	581
68	4624	3631	9½	8	8	82.3	12	0	476	11.33	1.45	16.73	502	350.7	11.76	83 232	6.852.768	583
70	4900	3848	9¼	8	10	81.71	12	0	502	11.66	1.475	18.08	542½	378.9	12.37	88.200	7.206.822	583
72	5184	4071	9	9	0	81.	12	0	530	12.	1.50	19.53	586	409.3	13.00	93.312	7.558.272	581

The Surface in the Flues is taken at Half.

Thefe have Two Boilers.

The different columns of this table explain themſelves, except the great product *per* minute. This is the effect of the engine expreſſed in a convenient manner, to ſeparate it from all conſiderations of the diameter or lift of the pumps, or of the number of ſtrokes which the engine makes in a minute; being the multiple of all theſe, and is thus obtained. Multiply the ſquare of the diameter of the cylinder in inches, by the preſſure on each ſquare inch of the piſton, not expreſſed in pounds weight, but in the height of a column of water in feet; and this again is multiplied by the velocity of the motion of the piſton *per* minute. For example, a 26-inch cylinder: ſquare of diameter, (676) × 18 feet, the preſſure *per* ſquare inch in feet of water, = 12168 × 76.21 feet, the journey *per* minute, = 927323, the great product *per* minute, as *per* table. The table is calculated upon the ſuppoſition that the preſſure upon each ſquare inch of the piſton is 8 lbs. avoirdupois, or 18 feet column of water.

The laſt column, or effect *per* minute of one buſhel *per* hour, is a comparative view of the effect of different-ſized engines, ſhewing the advantages of large engines in reſpect to ſmall, in the quantity of work they will effect in proportion to the coals they conſume.

To find the number of buſhels of coals which any of the engines will conſume *per* hour, calculate the internal ſurface of the cylinder in ſquare inches, and add to it three times the ſquare of the diameter, to allow for the piſton bottom, cylinder bottom, and the ſurface of the pipes which are within the cylinder. Next calculate the ſolid content of the cylinder in cubic inches, and find the proportion between the ſuperficial and the ſolid meaſure of the cylinder: according to the number of this proportion, find a number in the following table for a diviſor.

Proportion of the Surface of the Cylinder to its Capacity in ſquare and cubic Inches.	Effect of one Buſhel *per* Hour.	Differences.
1	98	
		90
2	188	
		85
3	273	
		76
4	349	
		65
5	414	
		54
6	468	
		44
7	512	
		33
8	545	
		22
9	567	
		11
10	578	
		0
11	578	
		8
12	572	

Laſtly, cut off three places of figures from the great product *per* minute, and dividing by the diviſor, the quotient will be the effect of one buſhel *per* minute.

For example, a 72-inch cylinder: its circumference will be 226.3, which, multiplied by 135 inches, the length, gives 30550 ſquare inches; and adding thereto 15552, which is three times the ſquare of the diameter, we have 46102 ſuperficial inches; and the content of the cylinder is 549652 cubic inches, which is 11.9 times the number of the ſuperficial inches. By ſeeking in the laſt table for 11.9 or 12, we find the number 572 for the diviſor of the great product, after cutting off its three laſt figures, *viz.* 7558 ÷ 572 = 13 buſhels *per* hour.

By this way of finding the proportion between the ſurface and the content of the cylinder, an allowance is made for the loſs of ſteam which takes place from condenſation, when it enters into the cylinder at every ſtroke, after it has been cooled by the injection thrown into it.

The quantity is very conſiderable, and forms the greateſt objection to this form of the ſteam-engine. An attentive obſervation to the action of an engine will ſhew that there is a waſte, but not the quantity in which it takes place. The moment the regulator is opened, when the piſton is at the bottom of the ſtroke, the ſteam may be perceived to iſſue from the ſnifting-valve with a ſtrong puff, becauſe the ſteam is more elaſtic than air by one or two pounds *per* ſquare inch; but as the piſton riſes, this ſteam diminiſhes, and ſoon ceaſes, and no more ſteam will iſſue during the whole riſe of the piſton.

To aſcertain the quantity of this loſs by condenſation, it becomes firſt neceſſary to know to what degree water is expanded, when converted into ſteam, at the preſſure of the atmoſphere; and compare this with the degree of expanſion which it requires to convert the water, which the boiler conſumes in a given time, into ſuch a quantity of ſteam as will fill the cylinder the requiſite number of times in the ſame period.

Mr. Beighton made an experiment at Griff engine, in Warwickſhire, on the degree of rarefaction of water when converted into ſteam, but without determining the temperature. The preſſure of the ſteam was juſt one pound upon the ſquare inch, as he determined by the ſteelyard of the ſafety-valve; and by our ſecond table, we find this to denote a temperature of about 216°. The cylinder of the engine contained 113 gallons of ſteam at every ſtroke, which, at 16 ſtrokes *per* minute, is equal to 1808 ale-gallons, or 1808 × 8 = 14464 pints of ſteam *per* minute. He found that the neceſſary ſupply of freſh water for the boiler, under theſe circumſtances, was about five pints *per* minute, to keep the ſurface of the water at a conſtant level; therefore, the relative bulks of the ſteam of one pound *per* inch preſſure, and the water from which it was produced, were as 5 to 14464, or as 1 to 2893 nearly. By an unaccountable miſtake, Deſaguliers, who relates the above experiment, deduces from the ſame data, that the expanſion is 13388, a number which has been frequently quoted by other writers. Mr. Beighton's experiment cannot be admitted as concluſive, becauſe the cylinder being cooled by the condenſing water at every ſtroke, the ſteam would be condenſed, and loſe much of its bulk in entering into the cold cylinder. But without making any allowance for that loſs, Mr. Beighton's experiment makes a greater degree of expanſion than has been found by others; and we ſhould not have mentioned this experiment at all, had it not been ſo frequently quoted after Deſaguliers with his enormous error, even by Belidor, Prony, and other foreign writers.

Mr. Smeaton made ſome experiments by weighing a Florence flaſk of four inches diameter, firſt when it was perfectly dry and empty, and afterwards when it was full of water; then pouring out all the water, except a ſmall quantity, he put the globe on the fire, and made it boil ſtrongly, till the laſt drop of water diſappeared, and at that inſtant he ſtopped up the mouth to retain the ſteam which was within it. The flaſk being now weighed, gave the difference of weight between the flaſk filled with water and with ſteam of an elaſtic force equal to that of atmoſpheric air; and deducting the weight of the empty flaſk from each of theſe

 experiments,

experiments, it gave the proportion of the bulk of the ſteam to that of the water: this, by a mean of ſix different experiments, he determined to be as $\frac{1}{2459}$. But ſuſpecting that ſome air was contained in the flaſk along with the ſteam, he inverted the mouth of it in water when it was filled with the hot ſteam, and found it to draw up the water in the ſame manner as deſcribed by captain Savery; but it was not quite filled with water, for a ſmall bubble of air remained in the flaſk, and this he eſtimated to be ſuch a portion of the whole content, as induced him to reduce his eſtimate of the expanſion from 2459 times to 1800 times; and this number, the ſame number that Mr. Watt had determined, he uſed in his calculations.

His inveſtigation of the quantity of ſteam deſtroyed by a given ſurface of the cold cylinder was as follows. The cylinder of the experimental engine was 9.9 inches diameter and 50 inches long: making the requiſite additions to its bottom and piſton, the internal ſurface was 2340 ſquare inches, and the ſolid content was 3940 cubic inches. The quantity of water neceſſary to ſupply the boiler at each ſtroke was found to be 8.5 cubic inches: therefore, $3940 \div 8.5 = 463$ times, which the 8.5 cubic inches of water muſt have expanded to fill the cylinder at each ſtroke. But ſuppoſing the water to have expanded 1800 times, the 8.5 inches $\times\ 1800 = 15300$ cubic inches of ſteam produced, which is 3.88 times the quantity employed to fill the cylinder. The difference of theſe numbers, *viz.* $15300 - 3940 = 11360$ inches of ſteam condenſed and loſt. This, divided by the number of ſuperficial inches on the ſurface of the cylinder, gives 4.9 cubic inches condenſed by every ſquare inch of ſurface.

It will be readily ſeen, that the proportion between the quantity of ſteam which muſt be produced, and the quantity which will be employed, will be leſs in large cylinders than in ſmall ones; hence the above is the extreme caſe; and in a ſimilar trial of a 52-inch cylinder, he found the waſte to be only 2.7 cubic inches for each inch of ſurface. Hence we ſee the reaſon for Mr. Smeaton's rule of making the proportion of the ſurface of the cylinder to its capacity the ground-work for the calculation of the quantity of coals.

In common engines, which are loaded to ſeven or eight pounds upon the inch, and are of a middle ſize, the quantity of ſteam which is condenſed in reſtoring to the cylinder the heat which it had loſt, is equal to the full contents of the cylinder, beſides what it really required to fill it; ſo that twice the contents of the cylinder are employed to make it raiſe a column of water equal to about ſeven or eight pounds for each ſquare inch of the piſton; or to take it more ſimply, a cubic foot of ſteam makes a ſufficient vacuum to raiſe a cubic foot of water about eighteen feet high, beſides overcoming the friction of the engine, and the reſiſtance of the water to motion.

In all Mr. Smeaton's experiments he obſerved the quantity of water which was evaporated in proportion to the coals, and found by a mean of a great number of experiments, that a buſhel of coals evaporated 12700 cubic inches of water, or 7.35 cubic feet; and eſtimating the expanſion at 1800 times, the buſhel of coals will produce 13230 cubic feet of ſteam, of little more in elaſticity than the atmoſphere, and about 214° of Fahrenheit's thermometer.

The Work actually performed by Atmoſpheric Engines in proportion to the Coals.—We ſhall firſt give the reſults of the performance of ſome old engines, according to Mr. Smeaton's account, before he began his improvements. The engine at Long Benton colliery, which was conſidered as one of the beſt in the neighbourhood of Newcaſtle, was tried by Mr. Smeaton in 1772; it was of the following dimenſions. Cylinder 52 inches diameter, ſtroke 7 feet. The pump was 12 inches diameter, and drew the water 61 fathoms high; and alſo an injection-pump 8 inches diameter, and 5 feet $7\frac{1}{2}$ inches ſtroke, which raiſed water 58 feet. This engine conſumed 8 bolls (of 2 cwt. 1 qr. $21\frac{1}{2}$ lbs. each) of coals, ſuch as are generally uſed for engines, in two hours and two minutes, when working at the rate of from $7\frac{1}{2}$ to 8 ſtrokes *per* minute, or $7\frac{3}{4}$ *per* minute at the medium.

The computations from theſe data are firſt to aſcertain the real weight of water in the pumps: the main pump being 12 inches diameter, and the injection-pump 8, the proportion of the areas of the two will be as the ſquares of their diameters, and their load in proportion to their height of column; therefore, as $144 : 64 :: 58$ feet high : 25.7 feet; that is, the whole load of the injection-pump will be equal 25.7 feet of the main column of 12 inches diameter; but this is, provided that the length of ſtroke was the ſame in both.

To reduce them to one, ſay as a 7-feet ſtroke, or 84 inches, : 67.5 in. :: 25.7 ft. : 20.7 feet of the column of the main pumps, ſay 21 feet.

Hence, the whole load conſiſts of the main column of 12 inches diameter, and 61 fathoms or 366 feet, and the injection-pump equal to 21 feet thereof, $366 + 21$ feet $= 387$ feet.

To obtain what Mr. Smeaton calls the great product, by which the powers of different engines can be compared, multiply the ſquare of the pump's diameter 144 inches $\times$ 387 feet lift $= 55728$, which multiplied by a 7-feet ſtroke $= 390096$, and again by 7.75 ſtrokes *per* minute $= 3023244$, the whole product or effect of the engine, without regard to coals, or without any allowance for the weight of the pump-rods, and the counterpoiſe of the engine.

The quantity of coals was 2 cwt. 1 qr. $21\frac{1}{2}$ lbs. $= 273\frac{1}{2}$ lbs. $\times$ 8 bolls $= 2188$ lbs. which divided by 88 lbs., the weight of a London buſhel, gives 24.86 buſhels conſumed in the whole time of the experiment, *viz.* two hours and two minutes, or 122 minutes.

To find the coals for one hour's work, ſay as 122 minutes : 60 min. :: 24.86 buſhels : 12.22 buſhels *per* hour.

Laſtly, the whole product 3023244, divided by 12.22, gives 247401 for the product or effect of one buſhel of coals *per* hour.

This engine was rebuilt according to Mr. Smeaton's plan, with the ſame cylinder of 52 inches and 7-feet ſtroke, but the pumps were enlarged to 12.2 inches diameter, and lifted in two columns each 24 fathoms 4 feet high. The injection-pump was 7 inches diameter, 5 feet 6 inches ſtroke, and lifted 70 feet 7 inches high.

In 1774 Mr. Smeaton tried the experiment, and found that when this new engine was working at the rate of twelve ſtrokes *per* minute, 2 cwt. 1 qr. 16 lbs. of the common engine coals ſupplied it 22 minutes.

From this he made a ſimilar computation to thoſe for the former engine. Square of 12.2 inches the diameter of the main pumps 148.84; ſquare of 7 inches the diameter of injection-pump 49; its lift $70\frac{1}{2}$ feet. Then ſay as 148.84 : 49 :: $70\frac{1}{2}$: 23.21 feet of the main column, if the lengths of the ſtrokes were equal; but as they are not, ſay as the long ſtroke 84 in. : 66 in. :: 23.21 ft. : 18.2; therefore the load of the injection-pump is equal to the load of 18.2 feet of height of the main column.

The total load then is equal to a barrel 12.2 inches diameter, twice 24 fathoms 4 feet, or 296 feet + 18 feet, *viz.* 314 feet of lift.

To obtain the great product, multiply the ſquare of the pump's diameter 148.84 by 314 feet; the height lifted =

46735.76, which multiplied by 7-feet ſtroke = 327150.32; and again by 12 ſtrokes *per* minute = 3925803.84, the whole product or effect of the engine, without regard to coals, or without allowance for the weight of the pump-rod, nearly 3 tons, and the counter-weight of the engine.

For the quantity of coals 2 cwt. 1 qr. 16lbs., or 268lbs., divide it by 88lbs., the weight of a London buſhel, and it makes 3.05 buſhels conſumed in 22 minutes, the time of the experiment; therefore ſay, as 22 min. : 60 min. :: 3.05 : 8.32 buſhels *per* hour.

Laſtly, the whole product 3925803.84, divided by 8.32, gives 471851 for the product, or effect of one buſhel of coals *per* hour. Therefore the effect of this new engine, compared with the former engine, is as 471851 to 247401.

To this computation, which is chiefly comparative between the two engines, we may add the following, to ſhew the preſſure upon each ſquare inch of the piſton. The area of the 52-inch cylinder is 52 × 52 = 2704 × .7854 = 2123 ſquare inches.

The weight of the column of water in the pumps, 12.2 inches diameter, will be about 50.9lbs. weight for each foot in height. For 12.2 × 12.2 = 148.84 × .7854 = 116.8, the ſquare inches in the area of the pump. Now, a cubic foot of water weighs 62½ pounds nearly; therefore divide 62.5lbs. by 144, the ſquare inches in a ſquare foot, and it will give .434lbs., which is the weight of a column of water one inch baſe and one foot high. Multiply 116.8 × .434 = 50.7lbs., the weight of the column of water in the pumps a foot high; and this multiplied by 314 feet, the whole lift equals 15919lbs., the total weight of water. Divide this number by 2123, the number of ſquare inches in the ſurface of the piſton, and it will give 7.48lbs. for the preſſure upon each ſquare inch, or 7½ very nearly.

Another method of readily finding the preſſure *per* ſquare inch in the piſton is thus. As the ſquare of the diameter of the cylinder (52 × 52 =) 2704 is to the ſquare of the diameter of the pump (12.2 × 12.2 =) 148.84, ſo is the height which the pump lifts, 314 feet, to 17.24, the height of a column of water, which, if it reſted on the piſton, would balance the water in the pump. Then multiply 17.24 feet by .434lbs., the weight of an inch ſquare of water one foot high, and the reſult is 7.48lbs. for the preſſure *per* ſquare inch, the ſame as before.

Since Mr. Watt introduced his improved engines, it has been cuſtomary to compare their effects by the number of pounds of water which they can raiſe to one foot high by the conſumption of a buſhel of coals, without regarding the time in which it is expended. To reduce theſe two engines to that ſtandard, we muſt ſay the firſt engine conſumed 24.86 buſhels in 122 minutes; therefore, as 24.86 buſh. : 122 min. :: 1 buſh. : 49 min.; that is, one buſhel will laſt 49 minutes. At every ſtroke, the pump draws up a cylinder of water, 12 inches diameter and 7 feet long, 387 feet high. This cylinder of water will weigh 343lbs.; for 12 × 12 = 144 ÷ .7854 = 113 inches, the area of the pump. This, multiplied by .434lbs., the weight of a column one inch ſquare, and one foot high, will be 49lbs.; and again, multiplied by 7 feet for the length, will equal 343lbs.

The quantity of coals conſumed in the firſt experiment was 24.86 buſhels: the experiment laſted 122 minutes, during which time the engine, working at 7¾ ſtrokes *per* minute, made 945 ſtrokes; then ſay, as 24.86 buſh. : 945 ſtrokes :: 1 buſh. : 38; therefore the engine makes 38 ſtrokes for every buſhel of coals which it conſumes.

At every ſtroke the engine raiſes 343lbs. of water 387 feet. Multiply 343 by 38, the number of ſtrokes, and it gives 13034lbs., lifted 387 feet by each buſhel of coals. Laſtly, 13034 × 387 = 5,044,158lbs. of water raiſed one foot high with a buſhel of coals.

The new engine conſumed 3.05 buſhels in 22 minutes, during which time it worked 12 ſtrokes *per* minute; it is therefore 264 ſtrokes: then ſay, as 3.05 buſh. : 264 ſtrokes :: 1 buſh. : 86.5, the number of ſtrokes which the engine will make for each buſhel it conſumes.

At every ſtroke the engine raiſes a cylinder of water, 12.2 inches diameter, 7 feet long, and weighing 354.8lbs. 314 feet high. Multiply this 354.8lbs. by the 86.5 ſtrokes which the engine makes for each buſhel of coals, and we have 30690, the number of pounds of water lifted 314 feet by each buſhel of coals. And laſtly, 30690lbs. × 314 feet = 9,636,660lbs. of water lifted one foot high with each buſhel of coals.

Mr. Smeaton's Directions for making Engines. — Mr. Smeaton made his engines with a wooden bottom to the piſton, as we have before noticed. This was becauſe wood communicates heat much leſs rapidly than metals. The piſton is kept much cooler than any other part to which the ſteam has direct acceſs, not only from the water which is poured upon it to keep it tight, and prevent the leakage of air into the cylinder, but alſo becauſe it receives the firſt and moſt direct action of the cold injection-water: and as the ſteam in entering the cylinder through the ſteam-pipe firſt meets the cold ſurface of the piſton, it is thereby condenſed in a greater degree than by an equal portion of the internal ſurface of the cylinder. By covering the bottom of the piſton with wood, it will receive or conduct leſs heat from the ſteam; and for the ſame reaſon, the cold water, when it is thrown up againſt the piſton, will be leſs heated by the contact of it, the wood acting as a neutral body on the fluids, which alternately act againſt it.

The injection-cap, or jet, according to Mr. Smeaton, ſhould be a ſquare hole through a braſs plate, and rounded from the under ſide, that it may throw up a full bore. The middle of the jet ſhould not be directed to ſtrike the centre of the piſton bottom, but it ſhould riſe perpendicularly, ſo as to ſtrike the piſton bottom at right angles. That part of the injection-pipe which is within the cylinder ſhould be made of wood, or if of metal, wrapped round with tarred marline, or ſmall rope, to ſeparate the metal of the pipe from the contact of the ſteam, or hot water, which not only ſaves the condenſation of ſome ſteam, but by preventing the pipe becoming hot, that portion of injection-water which is contained in the pipe is kept cool, and the ſteam which afterwards flows through the pipe will enter in its cooleſt ſtate. The injection-ciſtern ſhould be placed as high as the building will admit, ſo as to give a ſmartneſs to the jet.

A pipe ſhould be applied beyond the ſnifting-valve, with a cock in it, which being partially cloſed, the ſnifting can be regulated, if it ſhould be found too great, ſo as to emit more ſteam than is requiſite. Mr. Smeaton alſo placed a ſmall air-cock on the upper part of the eduction-pipe, or ſome other part having free communication with the cylinder, for the largeſt engine. This was to be only of the ſize of a ſmall common beer-cock; and when the ſnift was properly regulated, this cock was to be opened as much as it could be, to allow the piſton to come fully down into the cylinder. We ſuppoſe this air-cock muſt have been found practically beneficial, or ſuch an experimental engineer as Mr. Smeaton would have diſcontinued to recommend it: but we do not know on what principles the admiſſion of air could be ſerviceable, unleſs it was to diminiſh the deſcending power of the piſton when it arrived near the bottom of the cylinder, and thus diminiſh that acceleration of the piſton, of which

we have before ſpoken in the deſcription of the action of the engine.

Laſtly, in adjuſting the engine to its work, to determine the proper degree of counter-weight, it was to be put together, and the pumps filled with water, but the buckets without the leathers, and the piſton without any packing. In this ſtate, a weight, equal to about 1lb. *per* ſquare inch, being laid upon the piſton, the engine was ballaſted at either end of the beam, as it might require, until it was found in exact balance. Then, when the piſton was relieved from its weight, it would have a counter-weight tending to draw it up with a force equal to 1lb. *per* ſquare inch. This was for engines of the largeſt dimenſions; but as the proportion of loſs by friction of the piſton and buckets is greater in ſmall cylinders and pumps, ſmaller engines muſt have 1½lb., and the ſmalleſt engines 2lbs. *per* inch. When it is not convenient to fill the pumps with water up to the top, allowance muſt be made for the difference of the pump-rods not being immerſed.

Mr. Smeaton expected his engines, which were calculated to be loaded with a neat burden of 8lbs. *per* ſquare inch, would, with the counter-weight as above, make their returning ſtroke rather quicker than the working ſtroke, and this he preferred.

The proper proportion of the counter-weight has been a matter of much mathematical inveſtigation by writers on the engine, particularly M. Boſſut; but it depends upon ſo many contingent circumſtances, that it would be impoſſible to apply any theorem to practice, even if the theory were eſtabliſhed; and the adjuſtment is eaſily aſcertained by experiment.

The deſign of the engineer in giving or allowing a preponderancy to the outer end of the beam, is ſimply that the buckets may deſcend, and that the piſton may riſe and allow the ſteam to fill the cylinder, without any further combination of apparatus being employed for that purpoſe. Now let us obſerve its operation, and the manner of adjuſting its quantity in an engine's firſt ſetting to work. Suppoſe the water already up to the top of the pump: the ſteam being admitted into the cylinder till it has driven out the air, the operator ſhuts the ſteam-cock, without ſupplying any injection; and the engine will make its firſt ſtroke, though very quietly, by the external condenſation from the ſurface of the cylinder: he then allows ſteam again to enter the cylinder, and according to the piſton's tendency to riſe, he ſuits his judgment to the degree of counter-weight neceſſary: if it riſes too ſlow, he puts iron or other ballaſt upon the pump-end of the beam; and if it riſes too quick, he places theſe weights on the piſton-end. We have then two important circumſtances to attend to in this regulation. Firſt, that the pump-bucket ſhall deſcend as quick as it can, but without ſuch force as ſhall occaſion a violent ſhock to ſtop the motion at the end of the ſtrokes; and ſecondly, that the piſton ſhall not be drawn up faſter than the ſteam-regulator (with the degree of opening that is given to it) can ſupply ſteam; for that would impede the diſcharging functions of the engine, or getting rid of the air and condenſing water; and unleſs theſe are performed punctually, the engine ſoon ceaſes to work. Now neither the air nor the water can be diſcharged inſtantaneouſly from the cylinder, but require a certain time, in proportion to the quantity of each, and the degree of ſtrength in the ſteam; and therefore the piſton muſt not riſe ſo quick as to prevent the ſteam acting on the air and condenſing water, which it will do if the engine has too great a counter-weight, and the ſteam is low; for if the piſton aſcends faſter than the boiler ſupplies ſteam, there can be no diſcharge, and after a ſtroke or two the engine will ſtop.

But this is on the ſuppoſition that the engine is working with its full intended velocity. When an engine is erected on a mine or pit which is ſinking, the quantity of water to be lifted by the pump being ſmall, the engine muſt work ſlow, and the counter-weight muſt be in proportion; the beam will nevertheleſs require an extra counterpoiſe at the pump-end, becauſe of the lightneſs of the pump-rods; but as the mine or pit becomes of greater depth, and ſucceſſive lengths of rods are applied for the different lifts of pumps, the weight muſt be diminiſhed, and at length transferred to the piſton-end of the beam, in ſuch quantity as to keep the engine under command; for as the velocity of the returning ſtroke depends upon the quantum of counter-weight, this muſt be regulated according to the quantity of water which this engine has to draw, or rather to the number of ſtrokes the engine is to make in a minute As this velocity is to be increaſed when the quantity of water increaſes, a greater counter-weight muſt be added; but it is not until the engine works at its intended load, that the counter-weight muſt be brought to the degree we have mentioned.

While an engine is working, as we have ſuppoſed, with a ſmall portion of its full load, the injection muſt be very ſparingly applied, ſo as to condenſe imperfectly within the cylinder, or the piſton will deſcend with ſuch velocity, and ſtrike upon the ſpring-beams with ſuch violence, as to beat every thing to pieces.

When a mine is going down, and the engine-ſhaft receives all the water from the different parts of the mine, the quickneſs of the engine's ſtroke muſt depend upon the uniform influx of the water, and the engine muſt be ſo accurately regulated to this quantity of water, as to ſup it up at every ſtroke. Now if this ſupping up is violent, the air will be drawn into the pumps at the concluſion of every ſtroke, and cauſe the engine to work irregularly; and, on the other hand, if the ſtrokes of the engine are not quick enough, the water will gain on the miners and prevent their working. The velocity, as we have before ſtated, muſt be regulated by the quantity of injection which will determine the motion of the ſtroke, and the counter-weight will regulate the time of the returning ſtroke: but a much better regulation of the velocity of the engine can be attained by the cataract, which we have before deſcribed.

Even when the engine comes to work with its full load and counter-weight, and when a proper injection is allowed to condenſe fully, the engine-man can retard or accelerate the returning ſtrokes of the engine, in ſome degree, by the regulation of the fire; for if the engine ſhould return too quick, he lets down the damper in the flue of the chimney; or if it is too ſlow, he raiſes the damper. By theſe means he can vary the action of the ſteam, on the lower ſide of the piſton, from one to two pounds on the inch, greater than the preſſure of the atmoſphere, which in a ſixty-inch cylinder will amount to 2800 pounds, and is a ſufficient latitude to make the engine return very quick or very ſlow, but does not alter the period of the working of the ſtroke.

Other Improvements on Newcomen's Engine.—Mr. Smeaton's improvements on the engine, as we have ſhewn, conſiſted only in proportioning its parts, but without altering any thing in its principle.

In 1759, Mr. James Brindley, the engineer who deſigned and executed the duke of Bridgewater's canal, obtained a patent for improvements in the ſtructure of the fire-engine. The boiler he propoſed to be made of wood and ſtone, with a caſt-iron ſtove or fire-place withinſide of it, and fur-

rounded on all ſides, ſo as to give its heat to the water. The chimney was an iron pipe or tube, alſo immerſed in the water of the boiler. This plan he expected would ſave a conſiderable portion of the fuel. The feeding-pipe for the boiler was to be made with a clack, to be opened and ſhut by a float upon the ſurface of the water in the boiler, ſo as to ſupply it with water always to the ſame level, without any care on the part of the engine-man. The great chains for the arches of the beam were to be of wood, and his pumps were alſo to be made of wooden ſtaves hooped together. Theſe are all the improvements mentioned in the ſpecification of his patent: but in the new edition of the Biographia Britannica, we are informed that, in 1756, Mr. Brindley undertook to erect a ſteam-engine near Newcaſtle-under-Lyne upon a new plan. The boiler of it was made with brick and ſtone, inſtead of iron plates, and the water was heated by internal iron flues of a peculiar conſtruction, by which contrivances the conſumption of fuel neceſſary for working a ſteam-engine was reduced one-half. He introduced alſo into his engine wooden cylinders, made in the manner of coopers' ware, inſtead of iron ones, the former being cheaper and more eaſily managed in the ſhafts; and he likewiſe ſubſtituted wood for iron in the chains which worked at the end of the beam. He had formed deſigns of introducing other improvements into the conſtruction of this uſeful engine, but was diſcouraged by obſtacles that were thrown in his way.

The moſt important improvement in the atmoſpheric engine was the application of it, by means of a crank and fly-wheel, to the purpoſe of turning mills. This was not much of invention to any one who had conſidered the action of a foot-lathe; but it does not appear to have been put in practice till a late period, or brought into any extenſive uſe till after Mr. Watt invented his engine. Mr. Jonathan Hulls had a patent in 1736, for working rowing-wheels at the ſide or head of a boat by the force of Newcomen's engine, and we believe he propoſed to employ a crank, to produce the rotatory motion of his wheels.

In 1759, Mr. Keane Fitzgerald propoſed, in the Philoſophical Tranſactions, a contrivance to work the ventilator by the fire-engine, for the benefit of thoſe who work in mines, where it is employed to draw off the water. By this contrivance the lever of the fire-engine, which works up and down, and performs at a medium about twelve ſtrokes in a minute, is made to turn a wheel conſtantly one way, and the number of ſtrokes is alſo increaſed to fifty or ſixty in a minute. The machine is deſcribed by three figures annexed to the memoir, and is conſidered as ingenious. It is ſtated that it may eaſily be made to turn a mill to grind corn, or a wheel to raiſe coals.

It is related in the Encyclopædia Britannica, that Mr. Fitzgerald took out a patent for communicating a rotative motion from the ſteam-engine, but we believe this is a miſtake. In the Edinburgh Review it is ſtated, that an atmoſpheric engine was employed at Hartley colliery, in Northumberland, as early as 1768, to draw coals out of a pit. It had a toothed ſector on the end of the working beam, working into a trundle, which, by means of two pinions with ratchet-wheels, produced a rotative motion in the ſame direction, by both the aſcending and deſcending ſtroke of the arch; and by ſhifting the ratchets, the motion could be reverſed at pleaſure. This engine had no fly-wheel, and went ſluggiſhly and irregularly. Who the inventor was is not mentioned.

A patent was taken out in 1769 by a gentleman of the name of Stewart, for an engine which produced a rotative motion by a chain going round a pulley, and alſo round two barrels furniſhed with ratchet-wheels, with a weight ſuſpended to the free end of the chain, which ſerved to continue the motion during the return of the engine. About the year 1778, Mr. Matthew Waſhbrough, of Briſtol, alſo obtained a patent for communicating a rotative motion from the ſteam-engine, by a method which was virtually the ſame as that at Hartley; only he added a fly-wheel, which we believe was then, for the firſt time, employed in the ſteam-engine. Two or three of theſe engines were erected, one at his own works, for turning lathes, &c. and alſo one at Southampton, at Mr. Taylor's works, beſides two or three for grinding corn; but, owing to the defective mode of communicating the motion, they were ſubject to ſuch irregularities as rendered them of little uſe.

The crank, which is now the univerſal method of communicating the motion of the engine to machinery, was, we believe, firſt applied to an engine at Birmingham. This method of converting the reciprocating motion into a continuous rotatory motion, was by employing the great beam to work a crank or train of wheelwork. As the real action of the engine was confined to its working ſtroke, it was ſoon found advantageous to equalize, as nearly as could be, the power of the working and returning ſtrokes. For this purpoſe, the rod which extended from the beam to the crank, and connected the engine and the mill together, and which is called the connecting rod, was made equal in weight to half the power of the engine, being made of caſt-iron of large dimenſions; and when the weight was not in the rod, it was placed on the beam at that end.

Suppoſe that by this means the engine is made to exert an equal force to turn round the crank in the aſcent and deſcent of the connecting rod, ſtill it remains to find ſome force which ſhall continue the motion in the interval of its change from aſcending to deſcending, and *vice verſâ.* To accompliſh this, it is neceſſary to connect with the crank or wheel-work a very large and heavy fly, which ſhall accumulate in itſelf the whole force of the engine during its time of action; and therefore continue the motion, and urge forward the working machinery, while the ſteam-engine is going through its inactive period of changing the ſtroke. This will be the caſe, provided that the reſiſtance exerted by the machine during the whole period of the working and returning ſtroke of the ſteam-engine, together with the friction of both, does not exceed the whole preſſure exerted by the ſteam-engine during its periods of action upon the crank; and provided the momentum of the fly, ariſing from its weight and velocity, be ſufficiently great; ſo that the reſiſtance of the work, during the changing of the ſtroke of the ſteam-engine, will not make any very ſenſible diminution of the velocity of the fly. This is evidently poſſible and eaſy, for the fly may be made of any magnitude; and being exactly balanced round its axis, it will ſoon acquire any velocity conſiſtent with the motion of the ſteam-engine. During the working ſtroke of the engine, it is uniformly accelerated; and by its acquired momentum, it produces the movement of the mill until the engine changes, and makes its returning ſtroke; but in doing this, its momentum is ſhared with the inert matter of the ſteam-engine, and conſequently its velocity diminiſhed, but not entirely taken away. The weight of the connecting rod, therefore, by preſſing on the crank afreſh during the returning ſtroke, increaſes the remaining velocity in the fly, by a quantity equal to the whole that it loſt during the inactivity of the engine. This muſt be acknowledged to be a very important addition to the engine; and though ſufficiently obvious, it is ingenious, and requires conſiderable ſkill and addreſs to make it effective.

Mr. John Steed, in 1781, had a patent for applying the crank to a ſteam-engine; and in the ſame year, the abbé

Arnal Canon of Alais, in Languedoc, entertained a thought of the ſame kind, and propoſed it for working lighters in the inland navigations, a ſcheme which is now ſucceſsfully practiſed in America, and in this country. His brother, a major of engineers in the Auſtrian ſervice, carried the propoſal much farther, and applied it to manufactures; and the Aulic chamber of mines at Vienna patronized the project. (See Journal Encyclopédique, 1781.) But theſe ſchemes are long poſterior to Mr. Hull's patent, or to Mr. Fitzgerald's propoſals, and are even later than the erection of ſeveral machines driven by ſteam-engines by Meſſrs. Watt and Boulton.

When the more improved engines of Mr. Watt came into uſe, many perſons tried to improve the atmoſpheric engines by adopting ſome of Mr. Watt's ideas: one of theſe was to employ valves to riſe and fall perpendicularly into a conical ſeat, for the alternate admiſſion of ſteam and cold water into the cylinder, inſtead of the ſliding regulator and injection-cock. Mr. George Curr, who publiſhed his Practical Coal-Viewer, or Engine-Builder's Companion, in 1796, at Sheffield, gives drawings of ſuch an engine, and tables for the proportions of all the parts, from which, as they contain information not given before, we have extracted the following particulars.

Mr. Curr's Table of Proportions for the Parts of Atmoſpheric Steam-Engines.

Cylinders.	Boilers.				Injection. The Ciſtern being 36 Feet above the Top of the Cylinder.				Scantling of the Working-Beams, 25 Feet long. Oak in a ſingle Piece.		Iron Shanks for Piſton	Beam-Centres.	Arch-head Chain.	Preſſure on the Piſton, at 7 lb. per ſquare Inch.
Diameter in Inches.	No of Boilers.	Diameter of the Boilers.	Diameter of the Feed-Pipe.	Diameter of the Steam-Pipe.	Water-way of Injection-Cock.	Square Hole for Jet.	Bore of Injection-Pump.	Bore of Injection-Pipe	Square of the Middle.	Square at the Ends.	Square of one of the four Shanks for the Piſton.	Diameter of the Beam-Gudgeons	Diameter of the Pins for the Chains.	
		Feet.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches	Pounds.
25	1	8$\frac{1}{2}$	2$\frac{1}{2}$	8	2$\frac{1}{4}$ by $\frac{7}{8}$	$\frac{3}{4}$	3$\frac{3}{4}$	3$\frac{1}{4}$	22 by 20	19 — 15	1$\frac{1}{4}$	3$\frac{3}{4}$	1$\frac{1}{4}$	3436.12
30	1	10$\frac{1}{2}$	3	9	3 — 1	$\frac{7}{8}$	4$\frac{1}{2}$	3$\frac{1}{2}$	24 — 22	21 — 16	1$\frac{1}{2}$	4	1$\frac{3}{8}$	4948.02
35	1	12$\frac{1}{2}$	3	10	3$\frac{1}{8}$ — 1	1	5$\frac{1}{4}$	3$\frac{3}{4}$	26 — 23	22 — 17	1$\frac{3}{4}$	4$\frac{1}{4}$	1$\frac{1}{2}$	6734.80
40	1	14	3$\frac{1}{2}$	12	3$\frac{1}{4}$ — 1	1$\frac{1}{8}$	6	4	28 — 25	24 — 18	2	4$\frac{1}{2}$	1$\frac{3}{4}$	8796.48
45	2	11	2 of 3	9	3$\frac{3}{8}$ — 1$\frac{1}{8}$	1$\frac{1}{4}$	6$\frac{3}{4}$	4$\frac{1}{4}$	30 — 27	26 — 19	2$\frac{1}{4}$	4$\frac{3}{4}$	1$\frac{7}{8}$	11133.04
50	2	12$\frac{1}{2}$	2 — 3	10	3$\frac{1}{2}$ — 1$\frac{1}{8}$	1$\frac{3}{8}$	7$\frac{1}{2}$	4$\frac{1}{2}$	32 — 29	28 — 21	2$\frac{1}{2}$	5	2	13744.49
55	2	13$\frac{1}{2}$	2 — 3$\frac{1}{4}$	11	3$\frac{7}{8}$ — 1$\frac{1}{8}$	1$\frac{1}{2}$	8$\frac{1}{4}$	4$\frac{3}{4}$	33 — 30	29 — 22	2$\frac{3}{4}$	5$\frac{1}{2}$	2 of 1$\frac{3}{4}$	16630.84
60	2	14$\frac{1}{2}$	2 — 3$\frac{1}{2}$	12	4$\frac{1}{4}$ — 1$\frac{1}{4}$	1$\frac{5}{8}$	9	5	35 — 32	31 — 24	3	6	2 — 1$\frac{7}{8}$	19798.08
65	2	16	2 — 3$\frac{3}{4}$	12$\frac{1}{2}$	4$\frac{1}{2}$ — 1$\frac{1}{4}$	1$\frac{3}{4}$	9$\frac{3}{4}$	5$\frac{1}{4}$	36 — 33	32 — 25	3$\frac{1}{4}$	6$\frac{1}{4}$	2 — 1$\frac{7}{8}$	23228.20
70	2	17	2 — 4	13	4$\frac{1}{2}$ — 1$\frac{3}{8}$	1$\frac{7}{8}$	10$\frac{1}{2}$	5$\frac{1}{2}$	38 — 35	33 — 26	3$\frac{1}{2}$	6$\frac{1}{2}$	2 — 2	26939.22

In all theſe engines, he ſuppoſes the length of the ſtroke to be nine feet, and that they work 8$\frac{1}{2}$ feet ſtroke in common work.

In 1793, Mr. Francis Thompſon had a patent for making the atmoſpheric engine work a double ſtroke, for the convenience of turning machinery by a crank; this he effected by employing two cylinders, one inverted over the other, and the piſton of both connected by one rod, which paſſed through the bottom, or rather the top of the inverted cylinder, and was connected with the beam: by this means the cylinder acted alternately to make an up or down ſtroke. This never came into uſe, for the engine was as complicated as Mr. Watt's, without any of his advantages.

Mr. Watt's Steam-Engine.—The principle of this valuable invention will be beſt explained by a ſtatement of the manner in which it originated, and the ſteps by which it attained its preſent degree of perfection.

Mr. James Watt was, in 1763, a maker of mathematical inſtruments at Glaſgow, and being a man of a truly philoſophical mind, and well converſant with all branches of ſcience, he was in habits of aſſociating with the moſt celebrated ſcientific men at that time in Scotland, particularly with Dr. Black, Dr. Roebuck, and Dr. Robiſon, then a young philoſopher. About this time he undertook to repair a working model of a ſteam-engine belonging to the univerſity of Glaſgow, and during this employment, obſerved the great loſs of ſteam from the condenſation of the cold ſurface of the cylinder, which we have before explained in Mr. Smeaton's inveſtigations, though the latter were not made till after Mr. Watt's. He obſerved that a great quantity of heat is contained in a very minute quantity of water, in the form of elaſtic ſteam; for when a quantity of water is heated ſeveral degrees above the boiling point in a cloſe digeſter, if a hole be opened, the ſteam ruſhes out with great violence, and in three or four ſeconds, the heat of the remaining water is reduced to the boiling heat. If the ſteam be condenſed, the whole of it will afford only a few drops of water; yet this ſmall quantity, in the ſtate of ſteam, carried off with it all the exceſs of heat from the water of the digeſter. Mr. Watt reaſoned, that if ſo great a quantity of heat is contained in a certain quantity of ſteam, the economical uſe of the ſteam was a matter of the firſt importance in the improvement of the engine, more than the conſtruction of the furnace, which had been the chief object of former efforts to improve the engine, the improvement of the application of the ſteam having been much neglected after it was firſt ſettled by Beighton.

The cylinder of the little model was heated when the ſteam was in it, ſo that it could not be touched by the hand; but before a vacuum could be made, it required to be cooled by the injection, and was then to be heated again by the re-entrance of the ſteam: this, he ſaw, could not happen, unleſs the heat was abſtracted from the ſteam, which muſt occaſion the condenſation and waſte of a conſiderable portion. His firſt enquiry was, what portion of the ſteam was thus waſted; but ſo very few experiments had been made, even upon the moſt eſſential part of the ſubject, that the real bulk of water, when converted into ſteam of a given heat, remained unknown, until he determined it by new experiments in the year 1764. The opinions which had been entertained concerning its bulk before that time were much beyond the truth, and could by no means be deduced from the very inaccurate experiments which were ſaid to have been made.

Thus furnifhed with data, he was enabled to afcertain that the lofs of fteam, in alternately heating and cooling the cylinder, was not lefs than three or four times as much as would fill the cylinder and work the engine. The boiling of water in an exhaufted receiver at low heats, which had been difcovered, we believe, by M. Coulomb, was about this time communicated to Mr. Watt; but it was neither known what thefe heats were, nor what progreffion they obferved under various preffures, before he made his experiments on that fubject. Thefe experiments pointed out another defect of the common fteam-engine, *viz*. that the injection-water thrown into the cylinder to condenfe the fteam becoming hot, and being in a veffel exhaufted of air, it produces a fteam or vapour, which in part refifts the preffure of the atmofphere upon the pifton, and leffens the power of the engine: this might be remedied by throwing in as much water as would cool the whole veffel below the point at which water boils in vacuo; but then it would increafe the firft-mentioned inconvenience, which is the deftruction of fteam that unavoidably happens upon attempting to fill a cold cylinder with that fluid. Others, who had conftructed fteam-engines, found, that as they made their exhauftion more perfect by making the cylinder colder, they increafed the confumption of fteam in a greater proportion than they gained power. Though it appears they were ignorant of the caufe, they were fo fenfible of the effect, that they contented themfelves with caufing the engine to raife a load equal to feven pounds upon the fquare inch of the area of the pifton; whereas the preffure of the atmofphere would have raifed much more, if the cylinder had been perfectly exhaufted.

Mr. Watt's firft attempt at the improvement of the engine was by employing a wooden cylinder, which would tranfmit the heat more flowly: this had fome effect, but did not anfwer in other refpects, and he was obliged to abandon it, as well as Mr. Brindley, who had before tried the fame thing. He then cafed his metal cylinders in a wooden cafe with light wood-afhes: by this, and ufing no more injection than was abfolutely neceffary for the condenfation, he reduced the wafte almoft one-half. But by ufing fo fmall a quantity of cold water, the infide of the cylinder was hardly brought below the boiling temperature, and there confequently remained in it a fteam of very confiderable elafticity, which robbed the engine of a proportionable part of the atmofpherical preffure.

It was not until the next year (1765) that Mr. Watt made his great invention of performing the condenfation in a feparate veffel from the cylinder. He conceived, that if a veffel, which he afterwards called the condenfer, was made to communicate with the cylinder by a pipe, and filled with fteam at the fame time, an injection being thrown into the latter veffel would condenfe the fteam therein, and caufe a vacuum. Under thefe circumftances, the elafticity of the fteam in the cylinder would caufe it to rufh into the veffel to reftore the equilibrium; but this fteam being condenfed immediately it entered the veffel by the continuance of the injection, the vacuum would ftill remain, and draw off the remaining fteam from the cylinder until none was left. Here then was the vacuum in the cylinder produced, without any neceffity for diminifhing the temperature below the boiling point. Having thus obtained the vacuum to caufe the defcent of the pifton, the fubfequent re-afcent could be obtained by cutting off the communication between the cylinder and the condenfer, and admitting into the former a frefh fupply of fteam from the boiler; but it was not neceffary to admit any frefh fteam from the boiler to the condenfer, as the vacuum produced therein ftill continued, and it would be ready to receive and condenfe the fteam from the cylinder, as foon as the pifton arrived at the top of it, ready to make another ftroke.

The firft difficulty which oppofed itfelf to this beautiful chain of reafoning was, how to continue the action, and prevent the feparate condenfing veffel from filling with the injection-water, and alfo how to get rid of the air. To fnift by blowing fteam into the veffel, in the manner of the former engine, would have caufed him as great a wafte of fteam from condenfation, as he would fave by all his difcovery. He then thought of condenfing without injection, fimply by the application of cold water to the outfide of the condenfer, on Savery's firft plan; and to get rid of the fmall quantity of water produced by the condenfation of the fteam, he intended to carry a pipe down from the condenfer to a depth of 34 feet, from the end of which the water would run off by its gravity. But the air which is carried over by the fteam would alfo accumulate by degrees, and could not be fo eafily evacuated; a fmall pump muft then be applied to draw it off, and keep the condenfer empty.

Mr. Watt at the fame time conceived, that it would be very advantageous to employ the preffure or expanfive force of the fteam to actuate the pifton in its defcent, inftead of the preffure of the atmofphere, as it would be more manageable than the other in its intenfity. Thus was the whole difcovery made in a day; and it only remained to invent the details of the mechanifm to carry it into effect, and to eftablifh by experiment the requifite proportions of the parts.

Mr. Watt's firft experiment on thefe new ideas was to try the effect of the feparate condenfer; but before he had made the apparatus for the experiment, he refolved to extract the condenfed water from his condenfer by means of the fame pump which fhould draw off the air, as this method would be applicable in all fituations.

The firft apparatus was a cylindrical veffel, fitted with a pifton, which could be drawn up in it to exhauft the air therefrom. This veffel was made to communicate, by means of a long pipe half an inch in diameter, with the cylinder of the engine, which was two inches in diameter, and ten inches long. The pipe had a ftop-cock, to cut off the communication at pleafure; and the cylindrical veffel, which was made of thin tin-plate, was immerfed in cold water. The pifton of the cylindrical veffel being preffed to the bottom to difplace the contained air, was then drawn up to leave a vacuous fpace, and the cylinder of the engine, having its pifton at the top, was filled with fteam. The cock in the communicating pipe being then opened, the pifton defcended with a velocity, which fhewed that the vacuum in the cylinder was almoft perfect; and he found, that when he ufed water in the boiler purged of air by long boiling, nothing that was very fenfibly inferior to the preffure of the atmofphere on the pifton could hinder it from coming quite down to the bottom of the cylinder. This alone was gaining a great deal; for in moft engines, the remaining elafticity of the fteam arifing from the heated injection-water was not lefs than one eighth of the atmofpherical preffure, and therefore took away one-eighth of the power of the engine.

Mr. Watt was fo much occupied in other bufinefs, that it took him much time to complete his machine, and bring the whole to bear, fo that he did not apply for his firft patent until 1768, which bears date 5th Jan. 1769, and is for his method of leffening the confumption of fteam and fuel in fire-engines. The fpecification contains the following principles.

"First. That the vessel in which the powers of steam are to be employed to work the engine, which is called the cylinder in common fire-engines, and which I call the steam-vessel, must, during the whole time that the engine is at work, be kept as hot as the steam that enters it; first, by enclosing it in a case of wood, or any other material that transmits heat slowly; secondly, by surrounding it with steam, or other heated bodies; and thirdly, by suffering neither water, nor any other substance colder than steam, to enter or touch it during that time.

"Secondly. In engines that are to be worked wholly or partially by condensation of steam, the steam is to be condensed in vessels distinct from the steam-vessels or cylinders, although occasionally communicating with them. These vessels I call condensers; and while the engines are working, these condensers ought at least to be kept as cold as the air in the neighbourhood of the engines, by applications of water, or other cold bodies.

"Thirdly. Whatever air, or other elastic vapour, is not condensed by the cold of the condenser, and may impede the working of the engine, is to be drawn out of the steam-vessels or condensers by means of pumps, wrought by the engines themselves, or otherwise.

"Fourthly. I intend, in many cases, to employ the expansive force of steam to press on the pistons, or whatever may be used instead of them, in the same manner as the pressure of the atmosphere is now employed in common fire-engines. In cases where cold water cannot be had in plenty, the engines may be wrought by the force of steam only, by discharging the steam into the open air after it has done its office.

N. B. This should not be understood to extend to any engine where the water to be raised enters the steam-vessel itself, or any vessels having an open communication with it.

"Fifthly. Where motions round an axis are required, I make the steam-vessels in form of hollow rings, or circular channels, with proper inlets and outlets for the steam, mounted on horizontal axles, like the wheels of water-mills. Within them are placed a number of valves, which suffer bodies to go round the channels in one direction only. In these steam-vessels are placed weights, so fitted to them as entirely to fill up a part or portion of their channels, yet rendered capable of moving freely in them by the means hereinafter mentioned or specified. When the steam is admitted into these engines, between the weights and the valves, it acts equally on both, so as to raise the weights to one side of the wheel, and by the re-action on the valves, successively to give a circular motion to the wheel; the valves opening in the direction in which the weights are pressed, but not in the contrary one, as the steam-vessel which moves round it is supplied with steam from the boiler, and that which has performed its office may either be discharged by means of condensers, or into the open air.

"Sixthly. I intend, in some cases, to apply a degree of cold, not capable of reducing the steam to water, but of contracting it considerably, so that the engines shall be worked by the alternate expansion and contraction of the steam.

"Lastly. Instead of using water to render the piston or other parts of the engines air and steam-tight, I employ oils, wax, resinous bodies, fat of animals, quicksilver, and other metals, in their fluid state."

Soon after his patent, Mr. Watt became associated with Dr. Roebuck, who established the Carron iron-works. They proposed establishing an extensive manufactory for such engines under the patent; and Mr. Watt began his first real engine of 18 inches cylinder, at Kinneil, near Borrowstowness. This was a sort of experimental engine, and was successively altered and improved till it was brought to considerable perfection. In the details of its construction, the greatest difficulty of all was in the packing of the piston, so as to be steam-tight; because Mr. Watt's principle did not admit of water being kept upon the piston to prevent the leakage, as in the old engines. He found great difficulties in procuring a cylinder sufficiently accurate, until a new method was introduced at Burham foundery, by Mr. John Wilkinson. In the old method of boring, the instrument which performs the part of cutting the metal was guided in its progress only by the incorrect form given to the cylinder by the moulder; and though it insured that every part of the cylinder should be circular, it gave no certainty that the cylinder would be straight. This was quite sufficient for the old engines, but Mr. Watt's engines required greater precision. Wilkinson's machine, which is described in our article CYLINDER, insures all the accuracy the subject is capable of; and if the cylinder should be cast ever so crooked, the machine will bore it straight and true.

Dr. Roebuck becoming embarrassed, from the failure of his vast undertaking in the Borrowstowness coal and salt works, was unable to prosecute the manufactory of steam-engines, and, in 1774, disposed of his interest in Mr. Watt's patent to Mr. Matthew Boulton, whose establishment at Soho, near Birmingham, was then the most complete in England, and conducted with the most spirit. A portion of the works was allotted to Mr. Watt, who erected a foundery, and the necessary works to carry his invention into effect, on a grand scale.

In consequence of the great loss of time, and the enormous expence necessary for bringing the engine to perfection, Mr. Watt was not able to produce any large engines, as specimens of his invention, until 1774; and found, from the difficulty of introducing them, that the term of his patent was likely to pass away before he should be reimbursed: he, therefore, applied to parliament for a prolongation of his term, which was granted for 21 years, by an act passed in 1775. With this encouragement, and with the advantage of Mr. Boulton's assistance in systematizing the manufacture of the parts, Mr. Watt soon produced many capital engines, which were erected in Staffordshire, Shropshire, and Warwickshire, and a small one at Stratford near London. He found it was necessary to admit a small jet of injection into the condenser, and to employ an air-pump of sufficient dimensions to extract both the condensed steam and injection-water, as well as the air; for the condensation, by the application of external cold, was not sufficiently rapid, and the engine was so much improved as to afford amply for the power requisite to work the air-pump.

The condensing of the steam, by injection into the eduction-pipe, was an idea as early as the other kinds of condensers, and was tried in the very first engine built at Kinneil; but the other imperfections of that machine, owing to its leaks and bad workmanship, made a bad vacuum; and this being attributed to the air which came in with the injection-water, Mr. Watt disused the injection into the condenser, until the size and expence of the tubulated condenser for large engines, made him resolve to sacrifice a part of the power of the engine to convenience, and to employ larger air-pumps. In an engine at Bedworth, three air-pumps were used, two below, which were side by side, and worked by chains from each side of the beam, and a third above these two, and between them in the middle: this third one received the hot water lifted up by the other two; and by lessening the surface exposed to the pressure of the atmosphere, extracted the water

with greater eafe. In 1778 he only employed two air-pumps for the largelt engines, one being double the area of the other, and in fucceeding engines ufed only one, as at prefent, which is the air-pump of Smeaton.

A fketch of one of thefe firft engines is given in *Plate* IV. *Steam-Engine, fig.* 4. The cylinder, and great beam, with its arch-heads and the pumps, ftood in the fame pofition as the former engines; but the cylinder, A, was fmaller in proportion to the load than thofe before ufed, as it was generally loaded to $12\frac{1}{2}$ pounds on the fquare inch. The cylinder was very accurately bored withinfide, to make it ftraight and cylindrical, and externally it was furrounded by a fecond cylinder, or jacket B B, leaving a fmall fpace, G, all round between the bored or internal cylinder, and the outer jacket B.

This fpace, G, communicated by a large pipe, F, with the boiler, and always remained full of fteam, fo as to keep the cylinder, A, at the fame heat with the fteam, and thereby prevent any condenfation within it, which would have been a much greater lofs than an equal condenfation from the external furface of the jacket B. The jacket, B, was furnifhed with a lid, C, which had a hole in the centre for the pifton-rod, *a*, to pafs through. The rod was made truly cylindrical, fo that the hole could be kept fteam-tight by a collar of oakum fcrewed round it at E. The inner cylinder, A, had a clofe bottom, and the jacket, B, joined to the fame, the cylinder being fitted with the pifton H H, as ufual; but the top of the internal cylinder, A, did not reach quite up to the lid of the jacket B, or outer cylinder; by which means the fteam had always free accefs to the top of the pifton, H, from the fpace, G, between the cylinders, and confequently from the boilers through F. At the bottom part of the inner cylinder there were two regulating valves, O and K, one of which, O, either admitted the fteam to pafs from the interftice, G, between the jacket and the cylinder, through a paffage, I, into the fpace of the interior cylinder below the pifton, or fhut out the fteam from that fpace at pleafure: the other valve, K, opened or fhut the end of the eduction-pipe M, which conducted to the condenfer L. The condenfer, L, was a clofe veffel, made of thin metal, and furnifhed with an air-pump N. The air-pump had valves, and a bucket, *b*, for exhaufting the air, and drawing off the water which was produced by the condenfation of the fteam, along with the air which is extricated from the water in boiling, and rifes with the fteam. The air-pump was conftructed nearly the fame as a common pump, except that it had a lid or cover on the top of the barrel, to keep the preffure of the atmofphere from bearing conftantly upon the bucket. The rod, *d*, of the bucket paffed through a ftuffing-box in the lid, and was fufpended by a chain from the great working beam of the engine. The condenfer L, together with the air-pump N, were placed in a large ciftern of cold water X, fituated generally under the floor of the engine-houfe, between the cylinder and the wall on which the beam refted, and fupplied conftantly with frefh cold water from a fmall pump worked by the engine, or the ciftern was placed outfide of the wall, between the wall and the pit of the pump.

The action of this engine is as follows: fuppofe fteam from the boiler to enter at F, and fill the fpace, G, between the jacket and the cylinder, and alfo the upper part of the cylinder above the pifton. The condenfer, L, is exhaufted of its air, by opening both valves, O and K, in the bottom of the cylinder, and allowing the fteam from the fpace, G, to blow through it, and through the valves of the air-pump: both valves are then fhut, and the external cold condenfes it fo as to leave a vacuum in the condenfer, whilft the cylinder, A, is all the while full of fteam, from the fpace G, both above and below the pifton H: the fteam-valve, O, being fhut, cuts off all communication with the under fide of the pifton from the fteam in G, or in the boiler, and at the fame time the exhaufting-valve, K, from the condenfer is opened, when the fteam rufhes from the fpace of the cylinder A, below the pifton, through the eduction-pipe M, into the vacuum of the condenfer, with great violence, till it comes in contact with the cold fides of the condenfer L, which is made of thin metal, and immerfed in cold water. Under thefe circumftances the fteam is immediately deprived of its heat, and reduced into water; more fteam immediately rufhes in from the cylinder, until it is exhaufted, and makes a vacuum beneath the pifton H. The fteam which is above the pifton ceafing to be counteracted by the fteam which was below it, preffes between the top of the pifton and the bottom of the lid, C, with its whole elaftic force, and caufes the pifton to defcend to the bottom of the cylinder, carrying along with it the beam, and raifing the pump-buckets at the other end. The exhaufting-valve, K, is then fhut, and the fteam-valve, O, opened, which, allowing the fteam to enter below the pifton, leaves it at liberty to rife; in which cafe, the fuperior weight of the pump-rods raifes the pifton to the top of the cylinder, ready to commence another ftroke.

The advantages that arife from this conftruction are: 1ft. The cylinder, being furrounded with the fteam from the boiler, is always kept uniformly as hot as the fteam itfelf, and is, therefore, incapable of deftroying any part of the fteam which fhould fill it, as the common engines do. 2dly. The condenfer being kept always as cold as water can be procured, and colder than the point at which it boils in vacuo, the fteam is perfectly condenfed, and does not oppofe the defcent of the pifton; it is, therefore, forced down by the full power of the fteam from the boiler, which is fomewhat greater than that of the atmofphere. 3dly. The elafticity of the fteam being employed to prefs down the pifton, inftead of the preffure of the atmofphere, the air does not enter the cylinder, or cool its interior furface; and the engine is not confined, as in the former engine, to work with its whole force, but it is only to adminifter fteam of a proper elafticity, and we can vary the force of the engine very confiderably, without lofing any more fuel than that for which we obtain an effect.

When an engine of the old form is to be erected, the engineer muft make an accurate eftimate of the work to be performed, and muft proportion his engine accordingly. He muft be careful that it be fully able to execute its tafk; but its power muft not exceed its load in any extravagant degree. This would produce a motion which is too rapid, and which, being alternately in oppofite directions, would occafion jolts, which no building or machinery could withftand. Many engines have been fhattered by the pump's drawing air, or a pump-rod breaking; by which accidents, the fteam-pifton defcends with fuch force and rapidity, that every thing muft give way. But in moft operations of mining, the tafk of the engine increafes, and it muft be fo conftructed, at firft, as to be able to bear this addition. It is very difficult to manage a common engine when it is much fuperior to its tafk: the only mode is, as we have defcribed, by the fupply of a fcanty injection; but the eafieft way is to work the engine almoft full loaded, and that only during a few hours each day, allowing the pit-water to accumulate during its repofe. This increafes the firft coft of the erection, and waftes fuel; the miners are alfo much incommoded with water during the inaction of the engine. Mr. Watt's engine can, at all times, be exactly fitted, during the working ftroke, to the load of work that then happens to be on it: it is only neceffary to adminifter fteam of a proper elafticity. At the firft erection of the

engine, it may be calculated equal to twice its task, supposing that the steam admitted above the piston is to be three or four pounds *per* square inch more elastic than the atmosphere; but when the engine is first set to work, it may be made to act with a small portion of its force, by using weaker steam; for when once the ebullition in the boiler is fairly commenced, and the whole air is expelled from all parts of the apparatus, it is evident that, by damping the fire, steam of half this elasticity may be continually supplied, and the water will continue boiling, although its temperature does not exceed 185° of Fahrenheit's thermometer. This appears, by inspecting our first table of vaporous elasticity.

The method now proposed has one inconvenience; for, while the steam is weaker than the atmosphere, there is an external force tending to squeeze in the sides and bottom of the boiler, which could not be resisted in a large boiler, if the difference was considerable, and common air would rush in through every crevice of the joints of the engine. The regulation of the velocity of the engine may be produced by diminishing the passage for the steam into and out of the cylinder; for this purpose, the exhaustion-valve K, by which the steam passes away from the cylinder, may be so constructed, that its mechanism will lift it more or less high from the conical seat in which it is lodged, and consequently the passage can be enlarged or contracted at pleasure, by the distance to which the valve is drawn up. The degree of opening given to the exhaustion-valve would determine the rate at which the steam would flow off from the lower part of the cylinder to the condenser, and consequently the velocity of the descent of the piston; also the degree of opening of the other, or steam-valve, O, would determine the rate of the ascent of the piston, by regulating the rate at which the steam could pass from the boiler into the lower part of the cylinder.

But to save the trouble of making the adjustment for the degree of opening of the working-valves, it is better to place a separate valve in some part of the steam-pipe F, which brings the steam from the boiler to the jacket of the cylinder; then if this valve, which is called the throttle-valve, and is solely for the purpose of regulation, be partially closed, so that it will not admit steam into the jacket as fast as the descent of the piston makes room for it in the cylinder, it is evident that the steam in the top of the cylinder, and in the space of the jacket, must expand itself to fill a greater space, and thereby become more rare than before, and press upon the piston with less force. And this mode of regulation, by diminishing the quantity of the supply of steam, rather than diminishing its elasticity in the boiler, has this advantage, that a very considerable increase of the load of the engine cannot stop its motion, although it may retard it, because the closing of the throttle-valve only diminishes the velocity of the motion, not the force which the engine is capable of exerting when moving under a still less velocity. Suppose the load is so increased as to make the engine move very slowly, the steam will flow through the valve into the jacket and top of the cylinder faster than the descent of the piston will make room for it, and in consequence it will accumulate, until it has acquired the same pressure as within the boiler, or a sufficient pressure to overcome the resistance to the piston, and make it descend.

The form of the engine represented in *fig.* 4. was that which Mr. Watt first employed in his single engines for pumping; and, in some cases, where atmospheric engines were altered to this plan, the old cylinder, being inverted, served for the jacket, or external cylinder, the new cylinder being little more than half the area of the old one. He afterwards adopted another form for the arrangement of the parts, in which the steam for the supply of the cylinder does not pass through the jacket, but enters from the steam-pipe through a valve immediately into the top of the cylinder; and though the jacket has a communication with the boiler, the steam admitted within it is only for the purpose of keeping up the heat, and preventing any condensation of the steam within the cylinder. In this way the jacket becomes less essential to the engine; and about the year 1778, Messrs. Boulton and Watt began to make the jackets of wrought-iron plate, about 1½ inch from the cylinder all round; and, in some cases, they laid the jacket aside, but found this an ill-judged economy, and returned to it again, as they perceived that it made a difference in the fuel.

This engine is represented in *Plate* IV. *fig.* 5. The cylinder, A A, like the former, is closed at top by the lid or cover C; but this lid is screwed to the top flanch of the cylinder itself, instead of the top of the jacket, which may be omitted or not in this form, because the current of steam from the boiler, for the supply of the cylinder, does not flow through it, as in the former engine. The steam is brought from the boiler to the cylinder by the pipe F, which appears like a circle, being cut across in the direction of its length: *f* is the regulating or throttle-valve in that pipe, and *d* the communicating passage into the top of the cylinder, immediately beneath the valve, so that through this the steam has always entry into the top of the cylinder to press upon the piston, in such quantity as the opening of the regulating-valve, *f*, will allow. W is the steam-pipe, which descends to the bottom of the cylinder, for the purpose of establishing a communication between the top and bottom of it, when the piston is to ascend; and O is the steam-valve, which opens or shuts that communication at pleasure. F is the exhausting-valve, which being opened when the steam-valve, O, is shut, allows the steam to pass off to the condenser, which may be considered as the same which we have before described.

Suppose the piston at the top of its cylinder, and all the parts (except the eduction-pipe M, and condenser, which are vacuous) full of steam; if the valve O be shut, the exhausting-valve K, being opened, will permit the steam contained in the lower part of the cylinder to pass by its elasticity, and rush into the vacuum of the eduction-pipe and condenser; and being there condensed, the rest will follow till none remains: then the steam, flowing through the throttle-valve, and passage *d*, into the top of the cylinder, presses down the piston into the vacuous cylinder, until it arrives at the bottom; the exhausting-valve, K, is then shut, and at the same time the steam-valve, O, is opened by the plug-frame: this suffers the steam from the boiler to rush into and occupy that small portion of the bottom of the cylinder beneath the piston, which being filled with steam of an equal density to that above it, there will be an equal pressure on both sides of the piston; and the opening of the valve, O, having made a free communication between the top and bottom of the cylinder, the piston is at full liberty to rise by the action of its counter-weight, until it arrives at the top of the cylinder, and then the steam-valve, O, is shut, and the exhausting-valve, K, opened, to make another stroke, as before.

The sketch in *fig.* 2. was taken from an engine Messrs. Boulton and Watt erected at Hull, in 1779; and this, with some slight variations in the manner of its action, which we shall afterwards describe, is the present standard engine for pumping water: the variation is, that the regulating-valve, F, is made to open and shut at every stroke, and for regulation, another valve is applied in the steam-pipe just before it arrives at F.

In the two engines which we have described, the piston descends in consequence of the pressure of the steam being

made to act upon it whilst there is a vacuum beneath; and the ascent is made, when the piston is placed in equilibrio, by an open communication being made between the upper and lower parts of the cylinder; and this will always be an exact equilibrium, not imperfect, as in the old engine, where the varying pressure of the steam and of the atmosphere always renders the circumstances in which the piston rises uncertain.

It is evident that the ascent of the piston may be as well performed in vacuo, provided the vacuum is made at the same time both above and below the piston. This form of the engine is represented in *fig.* 3, in which, as the same letters of reference are used, it is needless to repeat the description of the cylinder and piston. F is the valve which admits the steam to the top of the cylinder, to press upon the piston: this valve is shut when the engine makes its return or upstroke. K is the exhaustion-valve, placed close beneath the steam-valve F, instead of being at the bottom of the pipe W, which descends to the condenser, and gives off a branch, I, to the bottom of the cylinder: by this pipe the steam is always drawn off from the bottom of the cylinder, to keep a constant vacuum therein. Suppose the exhausting-valve, K, open, the steam in the top of the cylinder will also pass off to the condenser through the pipe W, and leave a vacuum in the whole cylinder: in this case the piston rises freely by the counter-weight to the top of the cylinder; and being arrived there, the exhausting-valve, K, is shut, and the steam-valve, F, opened. The steam from the boiler entering into the top of the cylinder, and pressing between the lid and the top of the piston, presses down the latter to the bottom of the cylinder, where being arrived, the steam-valve, F, is shut, to prevent the farther admission of steam from the boiler; and at the same instant, the exhausting-valve, K, being opened, the steam from the top of the cylinder passes off to the condenser, and this makes a vacuum above the piston, the same as was before made beneath it: in consequence, the piston is left at full liberty to rise by the action of the counter-weight, until it arrives at the top: the exhausting-valve, K, is then shut, and the steam-valve, F, opened, to make a fresh descent. The advantage of this construction is, that the whole time of the ascent of the piston is allowed for making the condensation; but this is found of little importance in practice, because the vacuum takes place almost instantaneously, when the exhausting-valve is opened, to allow the steam to pass off to the condenser.

Mr. Watt's Expansion-Engine.—This was a most important improvement, of which Mr. Watt had the first idea in 1769, but did not fully put it in practice until 1778. It consists in shutting off the farther entrance of steam from the boiler, when the piston has been pressed down in the cylinder for a certain proportion of its total descent, and then leaving the remainder of the descent to be accomplished by the expansive force of that steam which is already introduced into the cylinder. This gives the means of regulating the acting force of the engine, because the pins of the plug-frame can be placed in such a manner, as that the steam-valve shall be shut when the piston has descended one-half, one-third, one-fourth, or any other proportion; and so far the cylinder will be occupied with steam of the same elasticity as that in the boiler, which is usually about the same as the atmosphere. In order to press the piston farther down, the steam must expand; and though its elasticity will diminish, it will be enough to complete the stroke. It is plain that this can be done in any degree at pleasure, as the adjustment of the pins in the plug-frame can be varied in an instant; and according as the engine requires more or less power, to allow the steam to act with its full force upon the piston for a greater or less portion of its total descent. If this method of working an engine had no other advantage than the regulation of the power, it would not effect the end better than the throttle-valve; but by the expansive principle a great saving of steam is made. We have before observed, in describing the action of Newcomen's engine, that the motion of the piston is accelerated in its descent by the continued action of the pressure of the atmosphere whilst the load is constant, or even greatest at the first, considering the vis inertiæ. Mr. Watt's engine is the same, but in a less degree, when it has a throttle-valve, because the steam cannot then come to the piston, except in a limited quantity; but when the top of the cylinder is open to the boiler, or the throttle-valve fully open, the effect is the same as if the atmospheric air had free entrance into the top of the cylinder. Now by stopping the further entrance of the steam at a certain portion of the descent, the piston can be made to descend with an uniform velocity, by the expenditure of only a portion of that quantity of steam which would be required, if steam of its full density was employed to press it down to the bottom with an accelerated velocity.

But when the steam is shut off at a portion of the descent, the pressure on the piston is continually diminishing as the steam becomes more and more rare; and, consequently, the accelerating force which works the engine diminishes. The motion of the descent, therefore, will no longer be uniformly accelerated; it will approach much faster to uniformity; or it may even be retarded; because, although the pressure on the piston at the beginning of the stroke may exceed the resistance of the load, yet when the piston is near the bottom, diminution of the pressure may occasion the resistance to exceed the pressure; in this case the motion can only be continued by the momentum of the moving parts. Whatever may be the law by which the pressure on the piston varies, it is possible to contrive the connecting machinery in such a way, that the chains or rods at the outer end of the beam shall continually exert the same pressure to lift the pump-rods, or that the machinery shall vary its force according to any law which is found most convenient. This may be done on the same principle that the watch-maker, by the form of the fusee, transmits an equal pressure to the wheel-work, from a very unequal action of the main-spring. In like manner, by making the communication from the piston-rod to the pump-rod by means of chains, which wind upon arch-heads, formed to portions of a proper spiral instead of a circle, the force of the piston upon the beam and pump-rods can be regulated at pleasure, so as to produce an uniform effect.

This was the subject of Mr. Watt's patent, March 12, 1782, for certain improvements upon steam-engines, and certain new pieces of mechanism to be added to them. The specification of this patent, which is lodged in the Rolls chapel, states the invention to consist in shutting off the steam at a portion of the descent, as we have described, and applying and combining levers, or other contrivances, so that the unequal or decreasing action of the steam upon the piston shall produce an uniform effect in raising the water in the pump-barrels.

The action of the expansion of the steam on the piston is thus explained. Suppose the whole descent of the piston decimally divided, *viz.* into ten parts, and each subdivided, the varying pressure of the expanding steam on the surface of the piston at each division will be according to the following

table, which we have made out from the information given in Mr. Watt's ſpecification, and which is on the ſuppoſition that the cylinder is eight feet long, or an eight-feet ſtroke, and that the ſteam is ſhut off at one-fourth of the deſcent, or at two feet from the top: but the ſame law will hold generally as to theſe particulars. The preſſure of the ſteam in the boiler is ſuppoſed to be equal to that of the atmoſphere, or 14 lbs. *per* ſquare inch, and the load of water in the pumps equal to 10 lbs. *per* ſquare inch of the piſton's ſurface.

	Portions of the Deſcent from the Top of the Cylinder		Proportion of the Preſſure of the Steam on the Piſton to the whole Preſſure of 14 lbs. *per* ſquare Inch.	
	.05			
	.1			This is the full preſſure of 14 lbs. *per* inch, before the ſupply of ſteam is ſhut off.
	.15	Full ſupply of ſteam from the boiler		
	.2			
One-fourth, or	.25			
	.3		0.83	
	.35		0.714	
	.4		0.625	
	.45		0.555	
One-half, or				Or half the original preſſure; *viz.* $7\frac{1}{2}$ lbs. *per* ſquare inch.
	.55		0.454	
	.6	Supply of ſteam cut off, and the deſcent is produced by the expanſion only	0.417	
	.65		0.385	
	.7		0.375	
Three-fourths,	.75		0.333	Or one-third the original preſſure; *viz.* $4\frac{2}{3}$ lbs. *per* ſquare inch.
	.8		0.312	
	.85		0.294	
	.9		0.277	
	.95		0.262	
Bottom of cylinder	1.		0.25	Or one-fourth the original preſſure; *viz.* $3\frac{1}{2}$ lbs. *per* ſquare inch.
			11.583	

Upon this the ſpecification remarks, that the ſum of all the varying powers is greater than fifty-ſeven hundredth parts of the original power multiplied by the length of the cylinder, whereby only one-fourth of the ſteam neceſſary to fill the cylinder is employed, and the effect is more than half that which would have been produced by the cylinder full of ſteam. Thus the ſum of all the numbers which expreſs the action of the ſteam, taken at twenty different places in the deſcent, is 11.583; whilſt the whole preſſure, repreſented by 1, and taken likewiſe at twenty different places, will be 20; it is therefore $\frac{11.583}{20}$, or $\frac{57}{100}$.

Dr. Robiſon's inveſtigation of Mr. Watt's expanſion-engine is as follows: Let C *r* I R (*fig.* 6.) repreſent a ſection of the cylinder of a ſteam-engine, and H H the ſurface of its piſton. Let us ſuppoſe that the ſteam was admitted, while H H was in contact with C *r*; and that as ſoon as the ſteam had preſſed it down to the ſituation E F, the ſteam-cock is ſhut. The ſteam, by expanding itſelf, will continue to preſs it down; and as the ſteam expands, its preſſure diminiſhes. We may expreſs its preſſure (exerted all the while the piſton moves from the ſituation C *r* to the ſituation E F) by the length of the line E F. If we ſuppoſe the elaſticity of the ſteam proportional to its denſity, as is nearly the caſe with air, we may expreſs the preſſure on the piſton in any other poſition, ſuch as M L or I R, by M *l* and I *c*, the ordinates of a rectangular hyperbola F *l c*; of which C E, C *r*, are the aſymptotes, and C the centre. The accumulated preſſure, during the motion of the piſton from E F to I R, will be expreſſed by the area E F *l c* I E; and the preſſure during the whole motion, by the area C *r* F *l c* I C. Now it is well known, that the area E F *c* I E is equal to C *r* F E, multiplied by the hyperbolic logarithm of $\frac{\mathrm{CI}}{\mathrm{CE}} = \mathrm{L} \cdot \frac{\mathrm{CI}}{\mathrm{CE}}$; and the whole area C *r* F *c* I C is $= \mathrm{C}r\mathrm{FE} \times \left(1 + \mathrm{L}\,\frac{\mathrm{CI}}{\mathrm{E}}\right)$.

Thus, let the diameter of the piſton be 24 inches, and the preſſure of the atmoſphere on a ſquare inch be 14 pounds; the preſſure on the piſton is 6333 pounds. Let the whole ſtroke be ſix feet, and let the ſteam be ſtopped when the piſton has deſcended 18 inches, or 1.5 foot. The hyperbolic logarithm of $\frac{6}{1.5}$ is 1.3862943: therefore, the accumulated preſſure C *r* F *l c* I C is $= 6333 \times 2.3862943 = 15114$ pounds.

As few profeſſional engineers are poſſeſſed of a table of hyperbolic logarithms, while tables of common logarithms are or ſhould be in the hands of every perſon who is much engaged in mechanical calculations, let the following method be practiſed: Take the common logarithm of $\frac{\mathrm{CI}}{\mathrm{CE}}$, and multiply it by 2.3026, the product is the hyperbolic logarithm of $\frac{\mathrm{CI}}{\mathrm{CE}}$. The accumulated preſſure, while the piſton moves from C *r* to E F, is 6333×1, or ſimply 6333 pounds; therefore, the ſteam, while it expands into the whole cylinder, adds a preſſure of 8781 pounds.

Suppofe that the fteam had been freely admitted during the whole defcent of the pifton, the accumulated preffure would have been 6333 × 4, or 25,332 pounds. Here Mr. Watt obferved a remarkable refult. The fteam expended, in this cafe, would have been four times greater than when it was ftopped at one-fourth, and yet the accumulated preffure is not twice as great, being nearly five-thirds. One-fourth of the fteam performs nearly three-fifths of the work; and an equal quantity performs more than twice as much work, when thus admitted, during one-fourth of the motion.

This information is curious and important, and the advantage of this method of working a fteam-engine increafes in proportion as the fteam is fooner ftopped; but the increafe is not great, after the fteam is rarefied four times, as the curve then approaches near to the axis, and fmall additions are made to the area. The expence of fuch great cylinders is confiderable, and may fometimes compenfate this advantage.

Let the Steam be ftopped at						Its Performance is multipled
$\frac{1}{2}$	-	-	-	-	-	1.7
$\frac{1}{3}$	-	-	-	-	-	2.1
$\frac{1}{4}$	-	-	-	-	-	2.4
$\frac{1}{5}$	-	-	-	-	-	2.6
$\frac{1}{6}$	-	-	-	-	-	2.8
$\frac{1}{7}$	-	-	-	-	-	3.0
$\frac{1}{8}$	-	-	-	-	-	3.2

The advantages of the expanfive method of working an engine are more fully obtained, when fteam of an elaftic preffure confiderably greater than the atmofphere is employed. The fecond table of expanfion fhews, that the increafe of the force of fteam, heated much above the boiling point, is very great by a fmall increafe of heat. For inftance, at 212°, the fteam is equal to the atmofphere: by only increafing the heat 40°, *viz.* to about 252°, we obtain a double preffure, or two atmofpheres; and the farther increafe of 30°, *viz.* to about 282°, makes an additional force, which renders it equal to three atmofpheres. Again, 24° higher, or about 306°, makes the fteam equal to four atmofpheres; and if it were practicable to go much farther, probably the fame law would hold. Now it follows as a confequence, that if fuch fmall acceffions of heat produce fo rapid an increafe of the expanfive force, fmall abftractions of heat from highly elaftic fteam will alfo reduce its elafticity in an equal degree, fo that fteam highly heated is more readily diminifhed in bulk by the application of cold than weaker fteam; that is, it can be more readily reduced in its preffure to any certain proportion of the preffure it had before. But if we would take away all its preffure, and leave a vacuum, we muft apply a fufficiency of cold water to take away all its heat, which is greater than weaker fteam, though not in direct proportion to its elaftic force.

Mr. Watt's firft fpecification (1769) defcribes the method of working by cooling or reducing the force of the fteam, without wholly condenfing it; but it has always been found moft advantageous to condenfe effectually, even though the power neceffary to draw out the injection-water from the condenfer is confiderable: the engine, in confequence of the greater perfection of the vacuum, is well able to afford this deduction. The moft advantageous application of highly heated fteam is on Mr. Watt's principle of admitting it in its full power, for a fmall portion of the defcent of the pifton; and then fhutting off the fupply, the remainder of the action is effected by the expanfive force of that portion of fteam already admitted. But to obtain the full advantage of the varying forces, it is neceffary to have fome contrivance, by which the effect of the engine, on the work which it is performing, fhall be uniform, or nearly fo. Mr. Watt's fpecification of 1782 contains a great number of different methods: firft, by chains acting upon fpirals, on the principle of the fufee; fecondly, by levers acting unequally upon each other; thirdly, by a large weight attached to the working-beam, at a confiderable height above the centre of motion. When the pifton begins its defcent, this weight will oppofe itfelf to the motion of the pifton, until the defcent of the latter has inclined the beam fo much, that the centre of gravity of the weight is perpendicularly over the centre of motion of the beam: the weight has then no effect on the engine; but after it has paffed this pofition, it muft evidently tend to aid the effort of the pifton to draw up the load of water in the pumps. And it is poffible fo to adjuft the weight in its pofition, quantity, and height above the centre of the beam, that it will very nearly equalize the diminifhing force of the pifton; but this muft be when the fteam is always ftopped at the fame proportion of the total defcent.

Fourthly: Another method, which is very ingenious, is to have two large cylinders or pumps, open at top and bottom, and each furnifhed with a pifton without valves. The piftons of the two are fufpended from the oppofite ends of the beam, fo that the defcent of one will produce the afcent of the other. The cylinders are filled with water, which is conducted by a large trough from the top of one cylinder to the top of the other, fo that the water is alternately transferred from one to the other. Suppofe each pifton at the middle of its refpective cylinder, the water will be equally divided between them upon their piftons, and will hang in equilibrio on the beam; but fuppofe one end of the beam depreffed, the pifton fufpended from the oppofite end will rife and raife up part of the water, which refts upon it, into the trough, by which it will run into the oppofite cylinder; and as the correfponding defcent of that pifton has made room for it, the water becomes unequally divided. When one pifton is at the top of its cylinder, the other will be at the bottom, and have the whole of the water refting upon it. Suppofe this pifton to be that one which is at the outer end of the beam, the fteam-pifton will be at the top of the cylinder; then if fteam be admitted, it will prefs down the fteam-pifton, and draw up the water in the cylinder at the outer end of the beam. The weight of this water oppofes the motion of the fteam-pifton, becaufe the whole of the water in the water-cylinder muft be lifted; but by the time the fteam-pifton has defcended one-third or one-fourth, and the fteam is fhut off, the preffure on the fteam-pifton begins to diminifh. The weight of the water on the water-pifton has diminifhed alfo, becaufe part of the water in it has run off by the trough, and entered into the oppofite cylinder, where its weight upon the water-pifton tends to aid the fteam-pifton in defcending; and this aid continues to increafe as the fteam-pifton defcends farther, by the water being regularly transferred from the afcending to the defcending water-pifton; until the whole of it refts upon that pifton which is at the bottom of its ftroke. It is evident that the fame action muft take place in returning, and therefore this contrivance is only applicable to a double acting engine, and fuch engines are not commonly ufed for pumping water.

The application of any of thefe ingenious contrivances to the vaft engines employed in pumping would be attended with great difficulties; and if attempted to be ufed to equalize the action of the expanfive principle, when ap-

plied to its fulleſt extent, would, we think, be impracticable: we mean, when ſteam of great elaſtic preſſure is employed, and when the ſtoppage of the ſupply is made to take place at a very ſmall portion of the deſcent. In this caſe, the ſtrain upon the centres of the ſnails or levers, ſufficiently oblique to equalize the action, would be beyond all bounds. Lord Stanhope has applied the principle of Mr. Watt's levers, in the moſt judicious manner, to the printing-preſs. (See PRINTING.) But in ſo ſmall a machine, worked only by the ſtrength of one man, the ſtrong caſt-iron frame of the preſs has been frequently broken.

We ſuppoſe it is for ſuch reaſons, that Meſſrs. Boulton and Watt have not, that we know of, applied theſe contrivances to any of their engines, but have contented themſelves with employing ſteam a little more than the preſſure of the atmoſphere, and ſtopping the ſupply at one-fourth or one-third of the deſcent, according to the circumſtances under which the engine works. In this caſe, the decreaſing preſſure in a large engine is not much greater than to counteract the acceleration, and aided by the momentum of the heavy working beam, pump-rods, and riſing column of water, produces nearly uniform motion.

Mr. Hornblower, about 1781, had a patent for a method of applying the expanſive principle of Mr. Watt in two ſucceſſive cylinders in ſuch a manner, as to approach more nearly to an equality of force, by which ſteam of great preſſure can be employed to act by its expanſion. This kind of engine, of which a deſcription is to be found in Mr. Watt's ſpecification of 1782, has ſince been brought to a great degree of perfection by Mr. Woolf, as we ſhall notice.

Deſcription of Meſſrs. Watt and Boulton's complete Single Engine. — *Plate* III. *fig.* 1. is taken from the engine at Chelſea water-works, for pumping water for the ſupply of London: it was erected in 1804, and is eſtimated at fifty horſes' power. — We have hitherto conſidered Mr. Watt's engine as being fitted up with the great wooden beam, and arch-heads, chains, and pumps, the ſame as the old engine. This was the form of the engine for ſome years; but ſince 1784, when Mr. Watt invented the parallel motion for his double acting engine for turning mills, that ingenious contrivance has been applied to the pumping engines, inſtead of the arch-head and chains, as being more correct in its action. Alſo, for about fifteen years paſt, they have employed caſt-iron working beams inſtead of wood. A B C is the beam, which is made of caſt-iron inſtead of wood, and is compoſed of two large plates, of the ſhape repreſented in the figure, put together at twelve inches diſtance from each other, leaving a ſpace between them, the centre or axis B paſſing through the middle of both plates. The axis lies on the floor D, which is ſuſtained by the wall E, built beneath the centre. Q is the cylinder, contained within a ſteam-jacket, compoſed of ſegments ſcrewed together. F F is the ſteam-pipe coming from the boiler G. *a b* is the piſton-rod, connected with the end, C, of the beam by links C, *b*; and whilſt the upper ends of theſe links move in the arc of a circle, with the end of the beam, the lower ends, *b*, are made to accommodate themſelves to the vertical motion of the piſton-rod *a*, by means of the rods, *c*, extending to the ſmaller links, *d*, which form a parallelogram. The motion of the parallelogram is governed by the bridle-rods, which move about a fixed centre *m*. The action of this contrivance is fully explained under the article *Parallel* MOTION; and it is enough for our preſent purpoſe to underſtand, that the lower ends, *b*, of the links, *b*, C, will aſcend and deſcend in a perpendicular right line. A ſimilar motion, but of half the quantity, is given to the rod, R, which works the air-pump, N, of the engine at the lower end, and the middle part of the rod has the plug-beam, R, attached to it, which has pins, or chocks, ſcrewed on it to actuate the handles, *x*, *y*, and *z*, of the mechaniſm for the valves, which mechaniſm is very different from that employed in the old engines, and even from that of the firſt engines of Mr. Watt. But to deſcribe all the varieties which have been adopted, would occupy a volume, and afford information of but little value.

The pump-rod, *p*, is ſuſpended at the end, A, of the beam by another parallel motion, and the upper part, S, of the rod is made of caſt-iron, and very maſſive, to have a ſufficient weight in itſelf to draw up the piſton, and make the returning ſtroke. The real pump-rod, *p*, is jointed to the heavy counter-weight S, and is poliſhed, like the piſton-rod *a*, that it may ſlide through a collar of leathers in the head of the pump Y, becauſe the pump is of that kind called lifting force-pumps; its bucket raiſes the water in aſcending, but it forces it through the air-veſſel T, and pipe X, which leads to a reſervoir two miles diſtant, in Hyde Park, and elevated 150 feet above the level of the water in the well where the pump draws from. This well has a communication with the river.

The cylinder, Q, is kept down by the weight of a pier of maſonry, on which it is placed, and large iron bolts, *n*, deſcend from the lower flanch to the groundſills, upon which the maſonry is built. Immediately before the pier is the condenſing ciſtern, M, which contains the air-pump N, the condenſer L, partly concealed, and hot-well *g*, and is kept ſupplied with cold water by the cold-water pump I, worked by the beam at the outer end, and the waſte runs off again into the well, ſo as to keep the water in the ciſtern always cold.

The valves, which muſt be opened and ſhut to produce the action of the engine, are four in number; *viz.* the upper ſteam-valve at F, the lower ſteam-valve O, and the exhauſtion-valve K, *fig.* 2, and a ſmall valve *l*, beneath the water in the ciſtern M, to admit the injection into the condenſer: but theſe parts are better explained in *fig.* 2, which is a ſection of the cylinder, air-pump, and condenſer on a double ſcale.

A, the ſection of the cylinder, in which the piſton, X, moves; F, the ſteam-pipe coming from the boiler; L, the condenſer; N, the air or diſcharging-pump; *m*, a paſſage or pipe from the pump L, to the condenſer N, in which paſſage is an occaſional communication by a hanging-valve at *m*, which ſhuts towards the condenſer; *l* is the injection-valve, to be lifted by the engine at every ſtroke, for the purpoſe of condenſing the ſteam in the condenſer L; *w* is the ſnifting or blowing-valve, placed outſide the condenſing ciſtern (of which M M is a ſection, on purpoſe to ſhew the contents); the ſnifting-valve, *w*, communicates with the condenſer by a pipe paſſing through the ſide of the ciſtern M, and is inſerted at the ſide of the condenſer; K is the exhauſtion-valve, to be lifted by the engine, and open a communication between the cylinder A and the condenſer L; O is the ſteam-valve, to be lifted by the engine, and open a communication between the lower part of the cylinder, and upper part thereof, through the ſteam-pipe *r*; and F is the upper ſteam-valve of the ſame kind, opening a paſſage from the boiler to the top of the cylinder; and thence by the pipe *r*, and valves O, K, to all parts of the engine.

We muſt now attend to the mechaniſm by which the engine is made to feed itſelf, and perform its reciprocations. The valves are lifted by means of a lever applied to each, within the iron box in which it is contained, entering into an opening in the ſtem of the valve; and a ſecond lever is fixed on the axis of the lever, on the outſide of the box, to be connected

with the levers and handles *x*, *y*, *z*, which open and ſhut the valves. There are three ſeparate axles, or ſpindles, placed parallel and above one another, and each has a handle or ſpanner *x*, *y*, *z*, by which it is moved, either by the hand, to ſtart the engine, or by the chocks on the plug-beam R, when the engine is in action. The two upper ſpindles, *x* and *y*, have ſhort levers projecting from them towards the cylinder; and from each of theſe levers a rod is ſuſpended, with a ſufficient weight, *o*, at the lower end to turn round the ſpindle, each upon its axis, in that direction which will cauſe the handles, *x* and *y*, to fly upwards. Alſo the lower ſpindle has a lever projecting from it, away from the cylinder, with a heavy weight, *n*, fixed at the end; but this being applied, on the oppoſite ſide, to the weights of the two upper handles *x*, *y*, the weight, *n*, cauſes the handle, *z*, to deſcend. Both the axles of the lower handles, *y*, *z*, have ſmall levers, or catches, 1 and 2, which act in the hooks of a double latch, or detent, *t v*, which is moveable upon a centre-pin ſituated between the two axles. The hooks of this detent are to detain the catches of the ſpindles, and prevent the handles, *y*, *z*, from moving by the action of their reſpective weights, until the detent is moved on its centre, ſo as to relieve the catches of the levers from its hooks *t*, *v*. But it is evident, from *fig.* A, that when only one catch, as 2, is hooked by the lower hook, *v*, of the detent, and conſequently the weight of its ſpindle is held up, if the other catch, 1, is moved by depreſſing its handle, *y*, ſo as to raiſe its weight in the act of entering the hook, *t*, of the detent, it will preſs the end, *t*, of the detent forwards upon its centre, and this at the ſame time preſſing back the hook, *v*, at the oppoſite end of the detent, releaſes the catch, 2, of the lower handle, *z*, therefrom, and the weight, *n*, on that ſpindle immediately falls.

The ſpindle of the upper handle, *x*, is devoted to opening and ſhutting the upper ſteam-valve F, having a lever which communicates by a rod, 2, with the lever, 3, of that valve; ſo that by preſſing down the handle *x*, it will ſhut the valve F. The weight *o*, which is applied to the upper ſpindle, tends to lift up the handle *x*, and open the valve F; and when the upper handle, *x*, is depreſſed, the valve will be ſhut; or when the handle is ſuffered to fly up by the action of its weight, it will open the valve.

The ſecond ſpindle, *y*, has a lever communicating with the lever of the exhauſting-valve K, by a rod 4. The weight *o*, applied to this like the former, tends to lift up the handle *y*, and draw open the valve; but when the handle, *y*, is depreſſed, the valve is ſhut, and in this poſition the catch, 1, is held down by the hook, *t*, of the detent before explained, and retains the valve ſhut.

Laſtly, the lower ſpindle, *z*, is for the lower ſteam-valve O, which is opened by the rod 14, when the handle, *z*, is ſuffered to fall down, and ſhut when the ſame is up, being held by the catch 2, and hook *v*. In all theſe the weight tends to open the valve; but when the valve is to be kept ſhut, the detent holds the weight up. Now, by removing the detent, the weight falls and opens the valve in an inſtant.

The upper ſpindle has no detent to detain it; but what is equivalent is a rod, 5, jointed to that lever of the middle axis which has its weight and rod, *o*, ſuſpended from it. The upper end of the rod, 5, is made with a loop, or long ſlit, in which works a pin at the end of a lever, 6, projecting from the upper axis towards the cylinder. The conſequence of this is, that while the middle axis is detained by its catch, and detent *t*, to keep the exhauſting-valve, K, ſhut; the lever, 6, of the upper ſpindle will be borne up by its pin reſting in the bottom of the loop of the rod, 5, ſo as to keep the weight from opening the upper ſteam-valve F, as long as the exhauſting-valve is kept ſhut; but when the catch, 1 *t*, of the middle axis is diſcharged, and its weight has opened the exhauſting-valve, the looped rod, 5, will no longer ſupport the lever, 6, of the upper axis, but allows its weight to deſcend and open the upper ſteam-valve: but at the ſame time the upper ſteam-valve, F, is not confined to be always open when the exhauſting-valve, K, is open; for the upper ſteam-valve may be ſhut by depreſſing the upper handle *x*, without affecting the exhauſting-valve at all, becauſe the ſlit, or loop, in the top of the rod, 5, allows that motion. This property muſt be attended to, becauſe the action of the engine, by expanſion, depends upon it. We have not before noticed the injection-valve, from which a long wire aſcends, and is attached to a ſtrap, 9, which winds upon the middle axis; therefore, when the middle handle, *y*, flies up by its weight, it winds the ſtrap, and opens the injection-valve at the ſame inſtant that the exhauſting-valve is opened.

The injection-valve, *l*, is placed to cloſe the orifice at the end of a ſhort curved pipe, which enters into the condenſer and turns up; and the pipe has a cock in it, between the valve and the condenſer, to cut off the communication, or to regulate the ſupply of injection when the valve is opened. This cock muſt be always ſhut when the engine is not at work, to prevent the condenſer filling with water.

Operation of the Engine.—We will now conſider the action of the engine. Suppoſe the fire lighted beneath the boiler G; all the valves are kept ſhut by preſſing down the two upper handles *x* and *y*, and lifting up the lower one, their reſpective catches detaining them in thoſe poſitions, until the ſteam is ſufficiently heated, and the engine is ready to work. In the quieſcent poſition of the engine, when it is at reſt, the counter-weight always draws the piſton fully at the top of its cylinder, as in the figure; the air-pump bucket will alſo be at the top of its barrel.

In order to prepare for ſetting the engine to work, all the three valves muſt be opened at once. This is done by relieving the ſpindles from their ſeveral catches, when the weights immediately open the valves. The ſteam enters through the valve F, into the top of the cylinder, and by the pipe *r*, through the lower ſteam-valve, O, into the bottom of the cylinder; alſo through the exhauſting-valve K, into the condenſer L, driving before it ſome air, which paſſes out at the ſnifting-valve *w*. At firſt, the coldneſs of the parts condenſes all the ſteam which enters; and it is not until all the iron, with which the ſteam comes in contact, is heated to the temperature of boiling water, that the ſteam ceaſes to flow from the boiler in a ſtream, and be condenſed as it arrives at the cylinder and condenſer; but after this, the ſteam acquires the ſame force in the cylinder and pipes that it has in the boiler: it then occupies every cavity and crevice of the engine, and in a little while diſplaces all the air in the cylinder, condenſer, and pipes, which paſſes out, and is diſcharged at the ſnifting-valve *w*. This valve is always covered with water in a ſmall ciſtern attached to the ſide of the large one, to enſure its tightneſs. Through this valve the air is diſcharged by the ſteam, not at every ſtroke, as in Newcomen's engine, but only at firſt ſetting the engine to work, and this operation is called the *blowing through*. It is well known when the cylinder and other veſſels are properly heated, and the air diſcharged, by a very ſmart crackling noiſe at that valve, like a violent decrepitation of ſalt in the fire; this noiſe being occaſioned by the water in the ſmall ciſtern producing a ſudden and rapid condenſation of the iſſuing ſteam when the air is all gone.

It being known by this sign that all parts of the engine are cleared of air, all the three valves are to be shut, by pressing and holding down the two upper handles *x*, *y*, and lifting up the lower handle *z*, in which situation its catch, 2, will retain it. This cuts off the farther supply of steam from the boiler, and also intercepts the passage of the steam from the cylinder to the condenser; and as the cold surface of the condenser still continues to condense a considerable portion of steam, there will soon be none left, and a vacuum will be formed in the condenser, while the cylinder both above and below the piston is full of steam. The vacuum in the condenser will soon become perfect from the external cold alone, though more slowly than when an injection is made.

In this state the engine is prepared for starting at a moment's notice, by the engine-man letting the two upper handles, *x* and *y*, rise up, by their respective weights: this opens the upper steam-valve, and the exhausting and injection-valves; the former admits the steam into the top of the cylinder, to press upon the piston; while the latter allows the steam, already in the lower part of the cylinder, to flow into the vacuous condenser; and at the same instant that he opens the injection-cock, the valve is lifted at the same time with the exhausting-valve: this admits a jet of cold water into the condenser, and condenses the steam as fast as it arrives from the cylinder, so that in an instant all the steam in the lower part of the cylinder will be drawn off and condensed. The pressure of the steam on the piston being now unbalanced by any thing beneath the piston, it descends and draws up the pump-buckets, and columns of water in the pumps, with a velocity proportioned to the pressure of the steam, and the diameter of the piston, compared with the height of the column of water in the pumps, and the diameter of the bucket: but the piston having descended about one-third of its stroke, a chock of the plug-frame, R, meets the upper handle *x*, and pressing it down, shuts off the steam from the boiler. That part of the handle on which the chock acts becomes perpendicular when the valve is shut, the handle being bent for that purpose; and the chock can therefore descend farther, and slide against the perpendicular part of the handle, which is straight, without producing any farther depression of the handle, at the same time that it keeps it down to the same point, so as to hold the valve shut. The piston, therefore, continues its descent by the farther expansion of the quantity of steam at first let into the cylinder; but having arrived at the bottom of its stroke, a chock on the opposite side of the plug-beam, R, seizes the middle handle, *y*, and presses it down, which pushes the rod, 4, until it shuts the exhausting-valve K, and also shuts the injection-valve by the strap and rod 9. When the catch, 1, of this handle, *y*, presses on the upper hook, *t*, of the detent *t v*, it relieves the catch, 2, of the lower axle *z*, and then the weight, *n*, causes the handle, *z*, to fall, and pulling the rod 14, opens the lower steam-valve O. Let us now consider the position of the engine; the middle handle, *y*, will be held down by its catch, 1, holding in the upper hook, *t*, of the detent, so as to keep the exhausting-valve, K, shut; and the upper steam-valve, F, is also kept shut, by the same means which kept it shut during the latter two-thirds of the descent of the piston.

Under these circumstances the piston is at liberty to rise by the action of the counter-weight S, because the opening of the lower steam-valve, O, has established a free communication between the top and bottom of the cylinder, and the steam in the top of the cylinder can flow through the pipe *r*, and enter the bottom of the cylinder, as fast as the piston rises, by the action of the counter-weight.

When the piston has returned to within one-third of the top of the cylinder, the chock of the plug-frame quits the upper handle *x*; but this handle cannot yet be thrown up by its weight to open the upper valve, because the rod, 5, from the lever of the middle axis bears up the short lever, 6, of the upper axis *x*; and thus the motion continues, till the piston arrives very nearly at the top of the cylinder: a chock on the plug-frame then seizes the lower handle *z*, and lifting it up, shuts the lower steam-valve; and the catch, 2, of the lower axis passing the lower hook, *v*, of the detent, moves it on its centre, so as to release the catch, 1, of the middle axis from the upper hook, *t*, of the detent. This being the case, the weight of the middle axis causes its handle, *y*, to fly up, and by the rod, 4, it opens the exhausting-valve; and by drawing the strap and rod, 9, it opens the injection-valve; at the same time the upper axis, *x*, losing the support of the rod 5, which kept it up, its weight carries up the upper handle *x*, and by pulling the rod, 2, it opens the upper steam-valve F.

The steam from the boiler is now admitted to press upon the upper surface of the piston, while the steam from the lower part of the cylinder beneath the piston rushes into the condenser, where being met by the cold injection, it is condensed, and makes a vacuum in the lower part of the cylinder, which brings down the piston to make another stroke.

At one-third of the descent, the plug-frame, as before, presses and holds down the upper handle *x*, to keep the upper steam-valve shut; and when the piston has arrived at the bottom, the plug-frame presses down the middle handle *y*, to shut the injection and the exhausting-valves; and in catching, this discharges the lower axis, and the weight thereof opens the lower steam-valve. The piston then rises by the counter-weight, and when at the top of its stroke, the plug-frame lifts the lower handle *z*, and shuts the lower steam-valve; and in catching, discharges the two other handles, which open the upper steam-valve, the exhausting-valve, and the injection-valve, and this produces the descent of the piston, as before.

If the air has been fully discharged from all parts of the engine by blowing through, the action of the air-pump does not begin until the injection-water and the air, which are extricated from the water in the boiling, have accumulated in some quantity in the condenser; then at every descent of the bucket, *d*, of the air-pump, it dips into the water contained in the bottom of the barrel N, and the water passes through the valves in the bucket: these valves shut when the bucket is drawn up, lifting all that water which is above them up to the top of the barrel, and there it is forced out through the hanging-valve *g*, into the hot-well *g*. The drawing up of the bucket at the same time makes a vacuum in the pump-barrel beneath it; and if this vacuum is more perfect than that in the condenser, which it will be, if the condenser contains either air or steam, it will press by its elasticity upon the surface of the water in the lower part of the condenser, and force it through the hanging-valve at *m*, into the lower part of the barrel, N, of the air-pump; and when all the water is gone from the condenser, the air or elastic vapour which is in the condenser will follow and enter into the pump, until the space of the barrel beneath the bucket is filled equally with the condenser.

This takes place while the pump-bucket is at the top of its barrel; and on the descent of the bucket, the space beneath it is diminished, until it compresses this rarefied vapour so much, that its elasticity will be sufficient to close the hanging-valve *m*, and to lift the valves in the bucket *d*, and pass through them into the space of the barrel above the bucket: and when the bucket has descended to the very lowest, the water contained in the bottom of the barrel, not being able to escape through *m*, must pass up through the valves, and rest upon the bucket *d*. When the bucket ascends, it carries

before it this water and air, and as it rifes the fpace of the barrel above the bucket diminifhes, and the rare vapour or air in it condenfes by being crowded into lefs fpace, until at laft it becomes equally denfe with the atmofpheric air, and then the water following it, drives it through the valve, g, into the open air.

The afcent of the bucket, d, left a vacuum beneath it, as before, and this drew a portion of the air or vapour from the condenfer into it, ready to be extracted by the next ftroke. As foon as the bucket begins to return, the difcharge-valve, g, fhuts, and prevents the atmofpheric air from entering into the pump. By this we fee, that if the vapour in the condenfer is fo rare that the whole contents of the barrel of the pump will only make a few cubic inches, when reduced to become equal to the preffure of the atmofphere, this fmall quantity will be effectually evacuated through the difcharge-valve g, becaufe the water refting upon the bucket follows the air, and will chafe every particle of it from the top of the pump, and then follow itfelf.

The air-pump of Mr. Watt's engine requires to be of large dimenfions, and the condenfer is generally of the fame fize, by which means the rarefaction of any elaftic vapour contained in the condenfer will be equal to half at every ftroke; that is, the air-pump will extract half the quantity of the elaftic vapour every time; becaufe, fuppofing the vacuous fpace which the bucket of the pump leaves beneath it, when it is drawn up, to be equal to the capacity of the condenfer, then the vapour in the condenfer muft expand itfelf to fill a double fpace, by which one half of it will enter into the pump, and be drawn out by the fucceeding ftroke, while the other half will remain in the condenfer.

The cylinder at Chelfea is four feet diameter, and eight feet ftroke, and the air-pump two feet diameter, and four feet ftroke: thus, their areas refpectively are as one to four, and their capacities as one to eight. But it muft not be confidered that this large pump, full of air, is to be drawn out of the condenfer at every ftroke; for, as we have ftated before, the vapour with which it is filled reduces itfelf to a fmall quantity before it comes to the denfity of atmofpheric air. At firft fight we fhould be led to conclude, that the pump affects the power of the engine, as a deduction, of as much power as the preffure of the air upon the furface of its bucket; but if we confider its conftruction, having a valve at g to keep off the preffure of the atmofphere, it is certain its bucket can have little weight upon the engine, until the bucket is near the higheft limits of the ftroke; and taking the fum of the refiftance, from the commencement of the ftroke to its termination, it will be found to be very little in comparifon with the power of the cylinder.

An air-pump of one-eighth the capacity of the cylinder is fufficient to keep the condenfer empty when it is a fingle engine. If a fmaller air-pump were employed, it muft be in action to lift out the air and water, for a greater portion of its ftroke.

In fact, whatever the fize of the air-pump may be, it will occafion little more refiftance to the engine than from the friction of its bucket, except during the time that it has actually opened the valve, g, to difcharge the air or water which it contains: before that period, the refiftance is only that of compreffing the vapour, an operation which begins at nothing, but increafes by an afcending proportion reverfe to that of the decreafe of the preffure of the fteam, when acting in the cylinder by expanfion, as we have before explained.

In Mr. Watt's early engines, the air-pump and condenfing ciftern were placed at the outer end of the beam; and there are fome reafons to prefer that mode of conftruction, where the building will admit of it. In this cafe, the pump-bucket being drawn up by the defcent of the pifton, the engine requires a lefs counter-weight than in the form juft defcribed, in which the air-pump muft be wholly worked by the counter-weight. Alfo, it is during the defcent of the pifton that the action of the air-pump is moft neceffary; and it is poffible that an engine, having the pump worked by the outer end of the beam, may make a better vacuum than when it is worked by the inner end, becaufe there may be fome, though a very flight impulfe given to the remaining air of the laft ftroke, by the rufh of fteam into the condenfer at the inftant the fteam-pifton begins to defcend, and the air-pump to rife; for no fooner is the exhaufting-valve opened, than the fteam rufhes towards the condenfer, and giving a momentary tendency to a plenum therein, may give a pufh to the air through the hanging-valve, between the pump and the condenfer; and hence it is reafonable to conclude, that more air will enter the pump by this means, than if it were left to its own expanfion.

It is neceffary that the parts appropriated to the condenfation of fteam fhould be kept as cold as poffible, and thofe intended for the operation, or paffage of the fteam, as hot as poffible; hence the air or difcharging pump and condenfer are placed in the ciftern of cold water, which is kept conftantly full by the cold-water pump, and a little running away into the well, to carry off the excefs of heat; and if the injection-valve is placed low in this ciftern, it will take the water in the coldeft ftate. The injection-valve and cock are feen in *fig.* 2.

As the condenfing apparatus is immerfed in water, to be kept cold, fo the cylinder fhould, if poffible, be immerfed in fteam, to be kept hot; for which purpofe, Mr. Watt from the firft ufed a cafing or jacket round the cylinder, and alfo at the top and bottom: this was attended with very beneficial effects, although it enlarged the fteam furface, and expofed the external jacket to a more rapid condenfation than would have taken place from the furface of the cylinder itfelf. But to have the vacuum as perfect as poffible, it is neceffary that the cylinder be kept up to fuch a temperature, as to prevent the leaft condenfation of the fteam upon the internal furface, either above or below the pifton; becaufe, if the fides of the cylinder were to be wet, as in the common atmofpherical engine, the vacuum would be vitiated, as there would be occafioned by this wetnefs a moifture gradually forming to fteam, which the outfide cafing prevents, when filled with fteam from the boiler, and the heat which efcapes from the furface of the jacket does not injure the operation of the engine; but if it were poffible to cover this outward cafe again with any fort of fubftance which would entirely prevent the tranfmiffion of heat from the cafing, it would fuperfede the ufe of the jacket altogether, and would apply with more advantage to the cylinder itfelf; but we do not know of any fubftance which will not admit this tranfmiffion more or lefs. Some of Meffrs. Watt and Boulton's beft engines we have feen furrounded by a cafe of polifhed copper, we believe outfide of the jacket.

In fmall engines, it is common to place the cylinder within the boiler, and it muft then be kept fully as hot as the fteam which enters it; but this is not practicable in a large engine, nor is it advifable in any cafe, becaufe the frequent repairs which the boiler requires muft derange all parts of the engine.

When the jacket is ufed, a fmall copper pipe is conducted from the fteam-pipe to keep it full. As the jacket of a large cylinder muft be expofed to be heated or cooled lefs than the metal cylinder to which it is attached, the unequal expanfion might break the joints; to avoid this, the jacket is made in two halves, put together in the middle of

the length, without any other attachment than that of entering into each other for three or four inches, with a cup which is packed with hemp and tallow. The ſteam-pipe has a ſimilar joint at *h*, *fig.* 2, which unites it to the box of the exhauſting-valve K, and will admit of drawing out a little.

Deſcription of other Parts of Mr. Watt's Engine.—In the drawing (*fig.* 1.) in our plate, the condenſer is repreſented at one ſide of the air-pump, in which ſituation it partly conceals the pump. In *fig.* 2. they are put into a different poſition for explanation, the condenſer being repreſented beneath the cylinder. The eduction-pipe is carried ſideways from the box in which the eduction-valve is ſituated, ſo that the condenſer can be placed in any ſituation which is convenient.

13, 13, are the catch-pins, which are firmly fixed to each end of the beam, and limit the motion of the engine by coming down to ſtrike upon the beams of the floor D, if the engine makes too long a ſtroke; and pieces of cork are laid on the floor to ſoften the blow with which it would otherwiſe ſtrike. It once happened to this engine, that the valve of the pump-bucket breaking, the engine ſuddenly loſt its load, or reſiſtance, which occaſioned the piſton to deſcend, and ſtrike on the ſpring-beams, or floor D, for two or three ſucceſſive ſtrokes, with ſuch violence as to break one of the beams; and at laſt the piſton ſtriking the bottom of the cylinder, the momentum of the beam forced down upon the rod ſo violently, as to bend the great piſton-rod quite crooked. To prevent ſimilar accidents, a ſmaller ſteam-pipe was added at the ſide of the vertical ſteam-pipe, communicating with the paſſage into the bottom of the cylinder: this pipe is kept cloſed by a valve; but if the engine deſcends ſo low as to ſtrike on the ſpring-beam D, the catch-pin, 13, of the beam ſtrikes a ſmall lever 10, and by the communication wire, 11, opens the valve, and lets the ſteam into the lower part of the cylinder, beneath the piſton, and this deſtroys the vacuum, ſo as to prevent the farther deſcent of the piſton.

There is alſo a ſmall ſpring-catch or detent, which tends to ſpring under the lever of the upper ſteam-valve, and prevent it from deſcending. This catch is held back by a ſecond catch, which is relieved when the catch-pin ſtrikes the lever 10, and then the firſt-mentioned detent, by retaining the ſteam-valve from being opened, prevents any danger of the engine making a repetition of the ſtroke while it has no load.

Boiler.—The boiler of the engine we have not mentioned before; it is ſet in a furnace, ſo as to receive the heat of the fire, and the flame paſſes through a long flue, which goes twice round the bottom part of the boiler, to give as much as poſſible of its heat to the water before it enters into the chimney. The ſteam-pipe, F, has a throttle-valve in it at 30, which regulates the ſupply of ſteam to the cylinder. This valve is not a conical ſpindle-valve, the ſame as the other valves of the engine, but is a circular plate of metal, made to fit the bore of the pipe, and is moveable upon an axis, which paſſes diametrically acroſs the plate; and the end of the axis, where it comes to the outſide, has a lever fixed on it to communicate motion to the valve, which being turned edgeways in the pipe, preſents ſcarcely any reſiſtance to the paſſage of the ſteam; but when turned flat acroſs the pipe, it ſtops its bore; and although it is not fitted with any extraordinary care, it is ſufficient to regulate the ſteam. This kind of throttle-valve is preferable, becauſe it can be moved by a very ſlight force.

Regulator.—There is a contrivance to regulate the velocity of the engine, by a ſmall pipe proceeding from the air-veſſel of the pump; it conveys water to the lower part of a ſmall vertical cylinder, into which a piſton is fitted, and loaded with a heavy weight; then if the engine works too faſt, ſo as to force more water into the air-veſſel than the main pipes, X, will carry off, it muſt make a greater preſſure and condenſation of the air in the air-veſſel, until the water is forced to run quicker through the main-pipe, and this preſſure being alſo communicated by the ſmall pipe to the regulating cylinder before-mentioned, cauſes its piſton to lift the weight and riſe up, and this motion is communicated by a wire to the throttle-valve, ſo as to cloſe it and diminiſh the ſupply of ſteam; or, on the other hand, if the engine works too ſlow, the preſſure in the air-veſſel muſt diminiſh, and then the loaded piſton will ſink and open the throttle-valve a ſmall quantity, to admit more ſteam.

It ſhould have been mentioned before, that the weight with which the piſton of this regulating cylinder is loaded, is ſo contrived, that it will increaſe in force as the piſton aſcends, and diminiſh as it deſcends. There are many ways of doing this, but the one adopted, in this caſe, is to load the piſton with a very heavy caſt-iron chain, ſome of the links of which fall upon the ground as it deſcends, and relieve the piſton from their weight; but as it aſcends, it lifts other links off the ground, and becomes more loaded, until it finds itſelf a place where the load will balance the preſſure of the water in the air-veſſel.

It is evident that, by this contrivance, the motion of the engine will at all times be ſo regulated, as to ſupply juſt the quantity of water deſired; but this quantity can be made greater or leſs, by applying a greater or leſs weight to the piſton, ſo that it will ſink more or leſs into its cylinder, before it will come to an equilibrium with the preſſure in the air-veſſel, and will thus open the throttle-valve more or leſs. But when the adjuſtment is once made, it will keep the engine working with regularity at that velocity.

In ſome of the lateſt engines erected by Meſſrs. Watt and Boulton, they have, by an ingenious movement, made the motion of this regulating piſton communicate with a long ſcrew, attached to the plug-beam, which regulates the chock that ſhuts the upper ſteam-valve at any required portion of the deſcent of the piſton. By this means, although the ſcrew is in conſtant motion with the plug-beam, the ſcrew is turned ſo as to regulate the chock on the plug, and meaſure out the quantity of ſteam which the engine ſhall have introduced into the cylinder at each ſtroke, to enable it to fulfil its taſk.

It is in theſe properties of the engine, by which it regulates itſelf, and provides for all its wants, that the great beauties of the invention conſiſt. M. Belidor, 80 years ago, ſpeaking of the old engine, ſays: "It muſt be acknowledged, that this is the moſt wonderful of all machines, and that nothing of the works of man approaches ſo near to animal life. Heat is the principle of its movement: there is in its tubes a circulation, like that of the blood in the veins of animals; having valves which open and ſhut in proper periods, it feeds itſelf, evacuates ſuch portions of its food as are uſeleſs, and draws from its own labours all which is neceſſary to its own ſubſiſtence." To purſue the idea, we may now ſay of the more perfect machine, that it has what approaches the appetite of animals, in taking that kind and quantity of food which its exigencies require, and in rejecting that which is unneceſſary. But we muſt explain theſe ſelf regulators more fully.

Apparatus connected with the Boiler.—In order to know the exact height of the water in the boiler, two gauge-cocks are employed, one of which reaches to within a little of the height or level at which the water ſhould ſtand, and another reaches a little below that level. If the water ſtands at the

desired height, the first-mentioned cock, being opened, will give out steam; and the other cock will emit water, in consequence of the pressure of the superincumbent steam on the surface of the water. But if water should issue from both cocks, it will be too high in the boiler; and if steam issues from both, it will be too low. This is the same contrivance which was used in Newcomen's engine; but Mr. Watt applied in his first engines a small vertical glass tube, which has a communication with the boiler by a copper pipe cemented to each end: one pipe, from the top of the glass tube, enters the boiler above the intended level of the water; and the other pipe, from the bottom of the glass tube, enters the boiler below the surface of the water. In this way, it is evident that the glass tube will always be filled with water to the same level as the water in the boiler, and may be graduated with inches, to inform the engine-man when the boiler requires a supply.

Another contrivance is a pipe descending beneath the surface of the water in the boiler, when at its intended level; and in the upper end of the pipe at the top of the house a whistle or mouth-piece is formed: then, if the water in the boiler sinks too low, the steam will issue at the pipe, and, passing through the whistle, will make such a noise as to call the engine-man to his duty, even if he should have fallen asleep. This contrivance is rendered unnecessary by a subsequent one, by which the boiler will always feed itself, exactly as fast as its evaporation of steam requires.

The boiler is kept constantly supplied with water, to repair the waste of evaporation, by means of a small pump 20, which draws hot water from the hot-well *g*, and raises it to such a height, that the water will run through a pipe, shewn by the dotted lines, into the cistern 14, placed over the top of the boiler, at an elevation of some feet. From this cistern a tube, 18, descends into the boiler, and terminates beneath the surface of the water therein, so as to feed the boiler with water. But as it is necessary that the water in the boiler should always be preserved at the same level, this feed-pipe is closed by a valve in the bottom of the cistern 14, which prevents the water running down into the boiler, until the level of the water subsides, and shews that it requires replenishing. A crooked arm, which is attached to the side of the small cistern 14, supports the short lever 15, 16, which moves upon a centre-pin. The extremity, 16, of this lever suspends, by means of the wire 16, a stone or piece of metal, which hangs just below the surface of the water in the boiler. The wire passes through a small stuffing-box in the top of the boiler, to prevent leakage. The other extremity, 15, of the lever is connected by a wire with a valve at the bottom of the cistern 14, which covers the top of the pipe 18; and this end of the lever is loaded with a sufficient weight to balance the stone in the boiler. Now it is a maxim in hydrostatics, that when a heavy body is suspended in a fluid, it loses as much of its weight as equals that of the quantity of fluid which it displaces. When the water in the boiler, therefore, is diminished, by the conversion of part of it into steam, the upper surface of the stone will be above the fluid, and its weight will consequently be increased in proportion to the quantity of its mass that is not immersed. By this addition to its weight, the stone will overcome the balance-weight on the end, 15, of the lever, causing the extremity, 16, of the lever to descend; and in consequence, by elevating the opposite arm 15, will open the valve at the top of the pipe 18, and thus gradually introduce a quantity of water into the boiler equal to that which is carried off by evaporation. This process is continually going on, while the water is converting into steam; and it is evident that too much water can never be introduced, for as soon as the surface of the water coincides with the surface of the stone, it recovers its former weight, and the valve at the bottom of the cistern, 14, shuts the top of the pipe 18, and prevents any more water entering the boiler, until the float or body, 21, descends by the diminution of the water therein.

When the engine is steadily at work, the stone subsides until it opens the valve to admit a regular stream of water, which will just equal the waste by evaporation; and then the operation will go on regularly, without any action of the float, until something is altered.

We have before stated, that the steam in the boiler is no stronger than the atmosphere; but there would still be great danger of the boiler's bursting, if the steam should accidentally become too strong: the boiler is, therefore, furnished with a safety-valve, which is so loaded, that its weight, added to that of the atmosphere, may exceed the pressure of the interior steam, when of a sufficient strength. As soon as the expansive force so far increases as to become dangerous to the boiler, its pressure preponderates over the pressure of the atmosphere, and the safety-valve is opened, when the steam escapes from the boiler, till its strength is sufficiently diminished; and the safety-valve shuts again, by the predominance of its pressure over that of the interior steam. By opening the safety-valve, the engine may be stopped at pleasure: and to effect this, a small rectangular lever, with equal arms, is fixed upon the side of the valve, and connected with its top. To one of these arms a chain is attached, which is conducted into the engine-house, and passes over a pulley from a horizontal to a vertical direction, so that it hangs like a bell-pull. By pulling it, the valve is opened, and the machine is stopped.

There is also another valve of safety, for the reverse of the object of the first-mentioned safety-valve: it opens internally, and is balanced by a small lever, and a sufficient weight to keep it shut, until the pressure of the steam within the boiler becomes much less than the external air, which then forces open the valve, and enters into the boiler, till the equilibrium is restored. It is evident that this valve can never be necessary so long as the engine is at work; but its use is to prevent the sides of the boiler being crushed in by the weight of the air, when it has done work, and the steam within it cools and condenses.

Self-acting Damper.— By another ingenious contrivance, the boiler is made to regulate the heat of its furnace, in proportion to the quantity of steam which the cylinder draws off from it. For this purpose, a damper or iron sliding-door is fitted into the flue, just where it enters the chimney; and a chain is conducted from it, over pullies, to any convenient situation, where the engine-man can pull it like a bell-pull, to draw up or lower down the damper, and by that means regulate the draught of air through the furnace, and the heat of the boiler.

To make the damper self-regulating, a large pipe of six or eight inches bore is fixed vertically through the top of the boiler: it is open at top and bottom, but the lower end descends nearly to the bottom of the boiler, so as to be always immersed beneath the surface of the water. Now the steam pressing on the surface of the water in the boiler, and the atmosphere pressing on the surface of the water in the open pipe, it is evident that the relative levels of the water in both will be at all times in exact proportion to the relative elasticity of the air and the steam: and if at any time the pressure of steam diminishes, by the heat of the furnace growing less, or by the engine drawing off more steam, the surface of the water in the open pipe will subside; and as there is a stone-float in this pipe, balanced in the same man-

ner as the feeding-float before defcribed, the defcent of the ftone is made to operate upon the chain of the damper, and draw it up fo as to increafe the draught of the furnace, until, by the acceffion of heat, the fteam recovers the intended preffure, and reftores the damper to its place. On the other hand, when the preffure of the fteam is on the increafe, either from the engine being retarded or ftopped, or from the furnace burning too faft, the preffure of the fteam on the furface of the water in the boiler raifes the water in the open pipe; and the ftone-float, then rifing by its balance-weight, clofes the damper, and diminifhes the draught, till the fteam fubfides to its defired force. By this means, the fteam is always preferved to the fame intenfity; a circumftance very neceffary to the regularity of the motion of the engine.

Steam-Gauge.—To afcertain the preffure of fteam with a greater degree of exactitude than by the load on the furface of the fafety-valve, which is liable to many uncertainties, Mr. Watt employs a fteam-gauge, confifting of an inverted fiphon, or bent tube, of glafs or iron; one leg of which is jointed to the fteam-pipe, and the other is open to the atmofphere. A quantity of mercury being poured into the tube, it will occupy the bent part which joins the two legs; and the furface of the mercury in one leg being expofed to the preffure of the fteam, while the external air acts upon the other, it is evident that the difference of level of the two furfaces will exprefs the preffure of the fteam in the height of a column of mercury.

When the tube is of glafs, this difference of level may be feen and meafured on a fcale; but when an iron tube is ufed, a fmall light wooden rod is made to float on the furface of the mercury in the open leg, and point out the height on a fcale of inches, fixed above the tube. But in this cafe the divifions, which are numbered for inches, muft be only half inches; becaufe, as the mercury defcends in one leg as much as it rifes in the other, the fcale reads double, to fhew the difference of level.

Barometer-Gauge.—Mr. Watt has alfo adapted a gauge, called a barometer, to indicate the degree of vacuum in his engines, an addition which is of important confequence to the good performance of the engine, to the profit of the proprietors, and the credit of the engineer; yet in many engines in London, we fee this important inftrument either out of repair, or wholly laid afide.

The form of this barometer can be underftood without a figure: it is a tube of glafs 30 inches long, filled with mercury, and applied to a fcale of inches, the lower end being immerfed in a cup, in the fame manner as the common barometer, or weather-glafs; it is, in fact, the fame thing as a barometer in every refpect, except that the vacuum is not made in the top of the tube, in the Torricellian manner, but by the engine. For this purpofe, a fmall copper tube is conducted from the condenfer, and cemented to the top of the glafs tube, by which means the furface of the mercury in the tube is relieved from the preffure of the atmofphere; and the weight of the atmofphere, which preffes upon the furface of the mercury in the bafon, will caufe it to mount up in the tube to a greater or lefs height, according as the vacuum is more or lefs perfect, or as the atmofphere is more or lefs heavy; which will be fhewn by a common barometer placed at the fide of the engine barometer.

The pipe which leads from the condenfer to the top of the barometer tube muft be provided with a cock, which fhould be fhut when the engine is blowing through, to prevent the fteam entering the tube, and blowing the mercury out of it: but the bafon for the mercury muft be made large enough to contain all the mercury, becaufe, when the engine is not at work, the air will leak in, and allow the mercury to defcend into the bafon.

It has been propofed to make the barometer in the form of an inverted fiphon, juft the fame as the common fteam-gauge, one leg being made to communicate with the condenfer, and the other left open to the air. In this way, the rife of the mercury in one leg produces a correfponding fall of the mercury in the other; but on this account, if the fcale is applied to one leg, the divifions muft be only half inches, that is, provided the two legs are of the fame bore; but if they are of different bores, the fcale muft not be half, but of a proper proportion, to fhew always the difference between the level of the furface of the mercury in the two legs.

Thefe tubes may be made of glafs; but if the quickfilver is not very pure, the alloy with which the venders of this article adulterate it is by conftant action brought to the furface, and, together with the vapour, make the tube fo foul, that no precifion can be obtained. Iron is the beft material for both parts of the tube, which fhould be correctly of one diameter, or elfe the refult will be erroneous, as we have before remarked; for it is difficult to graduate a fcale by experiment in an iron tube, where the difference of level of the mercury in the legs cannot be feen. This tube muft communicate with the condenfer by a fmall copper pipe, and a ftop-cock be placed between the gauge and condenfer. The index in this inftrument is the fame as in the fteam-gauge, *viz.* a light deal rod, which is put into the fhorter tube; and quickfilver being poured into it within three inches of the end, the rod is put into the tube, and floats on the quickfilver. It is almoft needlefs to remark, that the graduation on this inftrument muft be inverted with regard to thofe of a fingle tube.

The barometer fhews the perfection of the vacuum, or the preffure of the atmofphere to enter into the condenfer, whilft the fteam-gauge fhews the preffure of the fteam to efcape into the air. By adding the height of thefe two columns together, we have the preffure of the fteam upon the pifton, provided the throttle-valve is fully open, fo that there is no obftruction to the entrance of the fteam from the boiler into the cylinder. It would be interefting to have a fingle gauge made to exprefs this in one: nothing would be more eafy than to have a long glafs tube bent to an inverted fiphon, and one of the legs being connected with the fteam-pipe, and the other with the condenfer, the difference of level between the two furfaces would at all times exprefs the preffure on the pifton.

Counter.—In many of Mr. Watt's engines, a little apparatus is attached to the beam, to afcertain the number of ftrokes the engine makes in any given time: this contrivance is called the counter, and is a train of wheel-work, working like clock-work, commonly attached to the beam in fuch a manner, that every ftroke made by the engine moves one tooth, fo that the index tells how many ftrokes have been made fince laft examined. This is fo fhut up in a box, that no perfon can gain accefs to it but the one entrufted with the key. When the box is attached to the beam, the inclination of the beam caufes the pendulum to vibrate every time the engine makes a ftroke, and thus moves the counter round one tooth for every ftroke. In other cafes, the box containing the counter is fixed to the fpring-beam floor, and at every ftroke the beam ftrikes a fmall detent, and moves the counter one tooth. It was by the account of this inftrument that Meffrs. Boulton and Watt charged their portion of the favings for working their engines during the term of Mr. Watt's patent.

Conftruction of the Valves.—The fteam and eduction-valves are of that kind called button or conical fpindle-

valves. Mr. Watt, in his first essays, employed cocks, and also sliding-valves, such as the regulator or steam-valve of the old engine. But he found them always lose their tightness, after a short time. This is not surprising, when we consider that they are always perfectly dry, and almost burning hot. He was therefore obliged to change them all for spindle-valves, which being truly ground, and nicely fitted in their motions at first, are not found to get out of order by any length of time. Other engineers now use them commonly in the old form of the steam-engine, where, however, there is less necessity for them.

The manner of constructing these valves is as follows. *Fig.* 3. represents a valve, with its seat and box; suppose it one of the steam-valves; the box is at the end of the pipe which introduces the steam, and *h h* is the upper part of the pipe, which communicates with the lower part of the cylinder, or with the condenser. At *e e* may be observed a part more faintly shaded than the surrounding parts. This is the seat of the valve, and is a brass or bell-metal ring, turned conical on the outside, so as to fit exactly into a conical part, bored out in cast iron, of the pipe *h h*. This ring or seat is fitted in by cement; and the cone being of a long taper, the ring sticks firmly in it, especially after having been there for some time, and united by rust. The valve itself is a strong brass plate, D, turned conical on the edge, so as to fit the conical or inner edge of the seat. These two cones are very nicely ground into each other with emery. This conical joining is much more obtuse than the outer side of the ring *e*; so that although the joint is air-tight, the two pieces do not stick closely together. The valve has a spindle or round tail, D *c*, which is freely moveable up and down in the hole of a cross-piece extended beneath the ring or seat *e e*; and on the upper side of the valve is a strong piece of metal, D G, firmly jointed to it, one side of which is formed into a toothed rack.

A is the section of an iron axle, which turns in holes in the opposite sides of the valve-box; and one of these, where it passes quite through the side of the box, is nicely fitted by grinding, so as to be air-tight; and a stuffing of hemp, well soaked in melted tallow and rosin, is made to surround the outside of the hole, to prevent all ingress of air. The end of this axis projects a good way without the box, and carries a spanner or handle 3, which is connected by a rod with a lever, moved by the plug-frame. To the axis, A, is fixed a strong piece of metal, or sector, the edge of which is formed into an arc of a circle, having the axis, A, in its centre, and is cut into teeth, which work in the teeth of the rack D G, on the valve, and lift the same when the sector is moved. K K is a cover, which is fixed by screws to the top of the box F, and may be taken off, in order to get at the valve when it needs repairs. From this description it is easy to see, that by turning the handle 3, which is on the axis A, the sector must lift up the valve by means of its toothed rack D G, till the upper end of the rack touches the top or cover K; and turning the handle, 3, in the opposite direction, brings the valve down again to its seat.

The force requisite to lift up a large valve from its seat is very great, the valve being kept down by a pressure of the steam upon its upper surface while there is a vacuum beneath it. The valves of the Chelsea engine are nine inches diameter, and therefore contain ($9 \times 9 = 81 \times .7854 =$) $63\frac{1}{2}$ square inches, and each being pressed by at least 13 lbs., makes 826 lbs. weight to keep the valve down; and this should, if possible, be lifted in an instant, to admit the steam to pass off without delay. One method of balancing this weight is by means of a small piston, applied beneath the valve. Thus, the lower part of the pipe or box in which the valve is contained, is bored out to a short cylinder, and a piston is truly fitted therein, as shewn beneath K, *fig.* 2: a cover or bottom is screwed on to close the lower end of the short cylinder; and there is a small copper pipe from the jacket, which admits steam into the space of the short cylinder beneath its piston, while there is a vacuum in the box in which the valve is contained, and which is open to the upper surface of the piston. The axis of the valve being connected with the piston, it is evident that the action of the piston to ascend will counteract that of the valve to descend; and, therefore, by apportioning the area of the piston to that of the valve, it may be made to lift with the slightest force.

Even without this contrivance, which is only applied beneath the exhausting-valve, as is seen in the section, *fig.* 2, Mr. Watt invented a very simple and effective method of raising up the valves by levers. The force which holds down the valve is quite momentary; and the instant the valve is detached from its seat the pressure is over, although it has not risen more than a tenth of an inch; the force is, therefore, no impediment to the engine, but would be an inconvenient labour to the man who starts and stops it.

By Mr. Watt's contrivance, the lever is put in such a position when it begins to raise the valve, that its mechanical energy is almost infinitely great. Let *fig.* 3. represent the valve shut, which is supposed to have been just closed by the chock on the plug-beam in its descent coming in contact with the handle *x*, and depressing it, which is moveable with the axis X: on this same axis is another arm, X 2, connected by a joint with the leading rod 2 3, which is connected also by a joint with the lever 3 A, fixed on the axis, A, of the sector, contained within the valve-box. Therefore, when the chock of the plug-frame depresses the handle *x*, and turns the arm, X 2, round upon its centre, it pushes up the lever, 3 A, by means of the connecting rod, until the valve is closed, as shewn in *fig.* 3. At that time, the rod 2 3, and the arm, X 2, of the lever, are in one straight line, while the lever 3 A, (on the axis of the sector,) is at right angles to rod 2 3, which moves it; consequently the rod is acting with its greatest power to turn the axis A, upon which the sector is fixed. In this situation the valve is kept closed by the catch or detent before explained, which holds down the handle *x*, until it is wanted to be opened; the plug-frame then, by lifting the lower handle, relieves the catch, and the weight, *o*, applied to the axis turns it round into the position of the dotted lines, and the lever, X 2, draws the rod 2 3, and, by depressing the lever 3 A, opens the valve.

From this arrangement, the intelligent mechanic will perceive that, in this position, the force exerted by lever X 2 is extremely great to pull down the rod 2 3; and, at the same time, another great advantage arises from this disposition of the levers, which is, that any pressure, however strong, applied upon the valve to open it, would be ineffectual, as that force would be exerted to turn the lever X 2 endways, in the direction of the axis X, instead of turning it round, as shewn by the figure, which represents the valve shut, and retained in that position by the lever.

Construction of the Piston.—In Mr. Watt's first attempt, the greatest difficulty which he encountered was to make the great piston tight. The old and effectual method, by water lying on it, was inadmissible. He was therefore obliged to have his cylinders most nicely bored, perfectly cylindrical, and finely polished; and he made numberless trials of different soft substances for packing his piston, which should be tight without enormous friction, and long remain so, in a situation perfectly dry, and hot almost to burning.

After many trials, he settled the form of the packing which is now universally employed. The piston has a projecting rim

at bottom, which is fitted as accurately to the cylinder as it can be, to leave it at full liberty to riſe and fall through the whole length. The part of the piſton immediately above this is about two inches leſs all round than the cylinder, to leave a circular groove or channel, into which the hemp, or ſoft rope which is called gaſket, is rammed, to form the packing; then, to keep the packing in its place, a lid or cover is put over the top of the piſton, with a ring or projecting part, which enters into the circular groove for the packing, and preſſing upon it, the plate is forced down by ſcrews. The lower part of the groove round the piſton being made rounding, with a curve, this preſſure on the packing forces it againſt the inſide ſurface of the cylinder. The piſton muſt be kept ſupplied with melted greaſe; for which purpoſe a funnel is fixed on the top of the cylinder, with a cock and pipe to let the greaſe down. The ſtuffing-box in the top of the cylinder, round the piſton-rod, is packed with hemp in a ſimilar manner, a collar, with a hole through it for the paſſage of the rod, being ſcrewed down, to confine the packing in its place.

After all that has been done in this reſpect, it is probable that the greateſt part of the waſte of ſteam which we ſtill perceive in engines, ariſes from the unavoidable eſcape by the ſides of the piſton during its deſcent. If the piſton is packed ſo tight as totally to prevent the loſs, the friction is ſo increaſed as to fully outweigh the ſaving. But it is a fortunate circumſtance, that the performance of Mr. Watt's engine is not immediately deſtroyed, nor, indeed, ſenſibly diminiſhed, by a ſmall want of tightneſs in the piſton. In the atmoſpheric engine, if air enters in this way, it immediately puts at ſtop to the work; but in the new engine, although even a conſiderable quantity of ſteam eſcape paſt the piſton during its deſcent, the rapidity of condenſation is ſuch, that the diminution of preſſure is not conſiderable, and the waſte of ſteam is the greateſt inconvenience.

A great many ſchemes have been ſince tried to make better methods of packing a piſton, but none of them have been brought into uſe, except the metallic expanding piſton, which was propoſed by Mr. Cartwright, as we ſhall notice in deſcribing his engine. Something of the ſame kind, but not for ſteam-engines, is to be found in Leupold's Theatrum Machinarum Hydraulicarum, 1724.

The actual Performance of Mr. Watt's Engine with reſpect to Coals.—At the firſt eſtabliſhment of their engines, Meſſrs. Boulton and Watt charged their profits in proportion to the ſaving of fuel which their engine made, when compared with a common engine burning the ſame kind of coals. They had one-third of theſe ſavings paid them annually, or the payment was redeemed at ten years' purchaſe. It ſhould be obſerved, that Mr. Smeaton's improvements were introduced about the ſame time as Mr. Watt's, and therefore the compariſon was not with his engines, but with the former ones. It was Mr. Smeaton's rule, judging from ſome experiments made before him on ſome of Mr. Watt's early engines, to eſtimate Mr. Watt's engine at one-half the conſumption of fuel as his own for the ſame work, in large engines, or a ſtill greater proportion in ſmall engines, becauſe the waſte of ſteam is greater, and he reckoned his own at only one-half of the common engines, as he found them; therefore, Mr. Watt's will be four times as great in effect as the common engines.

As early as 1778, when Mr. Watt firſt eſtabliſhed his engine, we find his propoſals, deduced from experiment, were to raiſe 500,000 cubic feet of water one foot high with one cwt. of coals. He afterwards adopted the denomination of the number of pounds of water which could be lifted one foot high by a buſhel of coals as the ſcale for engines; if we reduce this to the latter term, it will be 24½ millions. Thus, 500,000 cubic feet × 62.5 lbs. the weight of a cubic foot of water, = 31,250,000 lbs. of water raiſed by 112 lbs. of coals. Then ſay, as 112 lbs. : 31,250,000 lbs. :: 88 lbs. the weight of a buſhel of coals, to 24,553,571, the number of pounds of water which will be lifted one foot high with one buſhel of coals. Mr. Watt was at that time in expectation of making a great improvement by adopting his expanſive method.

Mr. Smeaton, who was deſirous of promoting Mr. Watt's diſcovery, made an experiment in 1778, on an engine on the Birmingham canal, for returning into the reſervoir the water let down by the paſſage of boats through the locks.

The working cylinder was 20 inches, and the pump alſo 20 inches, lifting 27 feet, at the rate of 11 ſtrokes *per* minute, of 5 feet 9 inches length each. It worked for an hour with 65 lbs. of Wedneſbury coals.

When reduced, this experiment gives about 19 millions lifted one foot by a buſhel of coals. Thus, the area of the pump is (20 × 20 = 400 × .7854 =) 314 ſquare inches, × .434 lbs. = 136.27 lbs. weight for every foot in height, × 27 feet = 3679 lbs. the total weight of the column. The motion *per* minute is 63¼ feet (11 ſtrokes of 5 ft. 9 in. each), or 3795 ft. *per* hour, × 3679 lbs. = 13,961,805 lbs. raiſed 1 foot high *per* hour. The coals conſumed in the hour was 65 lbs.; therefore ſay, as 65 lbs. : 13,961,805 lbs. :: 88 lbs. : 18,902,156 lbs. raiſed one foot high with each buſhel of coals of 88 lbs.; load on the piſton 27 ft. of water, or (27 ÷ .434 =) 11.7 lbs. *per* ſquare inch.

When the engines were made to work with the expanſion, they were enabled to raiſe as much as 30,000,000 lbs., but this is when the engines are of the beſt conſtruction, and working under every advantage of the parts being tight and in the beſt order; for theſe circumſtances, when neglected, as they uſually are by the engine-keepers, make a moſt material difference in the reſult.

In the great ſcale of practical operations this nicety of management cannot be expected; and accordingly, from reports on the engines now working on the mines in Cornwall, which, with the exception of a few of Woolf's engines, are all on Mr. Watt's principle, and moſt of them conſtructed by Meſſrs. Boulton and Watt, taking the average of nine engines, bad, good, and indifferent together, they were found in Auguſt, 1811, to raiſe only 13,500,000 lbs. one foot high for each buſhel of coals which they conſumed.

But when it was known by the engine-keepers that their engines were under examination, they took ſo much pains to improve the effects, that by gradual increaſe, the engines, in 1815, lifted 21,500,000 lbs. taking the average of 33 engines. This information we obtain from the monthly reports of the engines which are working for draining the mines: theſe were begun in the year 1811, by the agreement of a number of reſpectable proprietors of the valuable tin and copper mines in Cornwall, who reſolved to have aſcertained the real work which their reſpective ſteam-engines were performing, as it was ſuſpected ſome of them were not doing duty adequate to the conſumption of fuel; and for the greater certainty of attaining their object, it was agreed that a counter ſhould be attached to each engine, and all the engines be put under the ſuperintendance of ſome reſpectable and competent engineer, who ſhould report monthly the following particulars in columns: *viz.* the name of the mine; the ſize of the working cylinder; whether working ſingle or double; the load *per* ſquare inch upon the piſton; length of the ſtroke in the cylinder; the number of pump-lifts; the depth in fathoms of each lift; diameter of pumps in inches; time during which they worked; conſumption of coals in buſhels during that time; number of ſtrokes during the time; length of ſtroke in the pump; load upon the whole area of the piſton in pounds; pounds

lifted one foot high by a bushel of coals; number of strokes *per* minute; and lastly, a column for names of engineers and remarks.

Messrs. Thomas and John Lean were appointed to the general superintendance, and since that time they have published monthly reports: from these we find the following are the three best engines working in 1816.

1st. Stray Park; a 63-inch cylinder, 7 ft. 9 in. stroke, single acting; being one of the three engines on the vast Dolcoath mine. The pressure on each square inch of the piston was 9 lbs. Its performance in four different months was 31, 31¼, 28, and 28½ million pounds of water lifted one foot by each bushel of coals.

2dly. Wheal Abraham mine; a single engine, 63-inch cylinder, working an 8 ft. 3 in. stroke, under a pressure of 9.4 lbs. *per* square inch on the piston. Its produce was 22, 29¼, and 32 million pounds of water raised a foot high with each bushel of coals. Another month, when the same engine was working with 7.9 lbs. on each square inch of the piston, its produce was 28,318,860 lbs.

3dly. Oatfield new engine; a 70-inch single cylinder, 8 ft. 6 in. stroke, 9.9 lbs. pressure. The effect in different months was 22½, 26½, 29, and 29 million pounds of water raised one foot high by each bushel of coals.

The editor of the Philosophical Magazine has drawn out from these reports the average performance of all the engines, as we have mentioned, and the whole of them, for every month up to the end of 1815, will be found in the 46th and 47th vols. of that useful work; as also reports upon Woolf's engine, of which we shall speak in another place. The original reports of Messrs. T. and J. Lean contain information highly interesting to the practical engineer.

In calculating the dimensions of an engine on Mr. Watt's principle to perform any given task, the engineer has less difficulty than in Newcomen's engine, because the pressure on the piston can be so much varied. It is advisable, in general, to take 10 lbs. pressure *per* square inch on the piston for the load; and then, in working the engine, if it becomes necessary, it can be diminished to 9 lbs. or even 7 lbs. or increased to 15 lbs. which is a great latitude for future contingencies.

We have before given the great waste of steam by condensation, on entering into the cold cylinder of the atmospheric engine, which is nearly as great as that which ultimately produces its action; it therefore takes double the supply of fuel which is requisite, if the waste could be avoided.

In the improved engine of Mr. Watt, about 1¼ of the quantity of the steam which is necessary to fill the cylinder must be furnished at each stroke; and it is probable that a considerable portion of this waste is from the leakage of the piston, as well as from condensation.

Mr. Hornblower's Double Cylinder Steam-Engine.—The intention of this improvement was to obtain a greater power by a complicated force of the steam, than was supposed could be done by its action in the simple way.

We are not to consider this engine as being on a different principle from Mr. Watt's, but as applying his principles of condensation and expansion in a different manner from what Mr. Watt does. Mr. Hornblower obtained a patent in 1781, for a machine or engine for raising water by means of fire, and the specification of the patent was as follows:

"First: I use two vessels, in which the steam is to act, and which in other engines are called cylinders. Secondly: I employ the steam after it has acted in the first vessel to operate a second time in the other, by permitting it to expand itself, which I do by connecting the vessels together, and forming proper channels and apertures, whereby the steam shall occasionally go in and out of the said vessels. Thirdly: I condense the steam, by causing it to pass in contact with metalline surfaces, while water is applied to the opposite side. Fourthly: To discharge the engine of the water used to condense the steam, I suspend a column of water in a tube or vessel constructed for that purpose, on the principles of the barometer, the upper end having open communication with the steam-vessels, and the lower end being immersed in a vessel of water. Fifthly: To discharge the air which enters the steam-vessels with the condensing water or otherwise, I introduce it into a separate vessel, whence it is protruded by the admission of steam. Sixthly: That the condensed vapour shall not remain in the steam-vessel in which the steam is condensed, I collect it into another vessel, which has open communication with the steam-vessels, and the water in the mine, reservoir, or river.

"Lastly, in cases where the atmosphere is to be employed to act on the piston, I use a piston so constructed as to admit steam round its periphery, and in contact with the sides of the steam-vessel, thereby to prevent the external air from passing in between the piston and the sides of the steam-vessel."

The following is a description of this engine by the inventor, as it was published in the Encyclopædia Britannica. Let A and B (*Plate* V. *fig.* 1.) represent two cylinders, of which A is the largest; a piston moves in each, having their rods, C and D, moving through collars at E and F. These cylinders may be supplied with steam from the boiler by means of the square pipe G, which has a flanch to connect it with the rest of the steam-pipe. This square part is represented as branching off to both cylinders: *c* and *d* are two cocks, which have handles and tumblers as usual, worked by the plug-beam W. On the fore-side of the cylinders (that is the side next the eye) is represented another communicating pipe, whose section is also square, or rectangular, having also two cocks *a*, *b*. The pipe Y, immediately under the cock *b*, establishes a communication between the upper and lower parts of the small cylinder B, by opening the cock *b*. There is a similar pipe on the other side of the cylinder A, immediately under the cock *d*.

When the cocks *c* and *a* are open, and the cocks *b* and *d* are shut, the steam from the boiler has free admission into the upper part of the small cylinder B, and the steam from the lower part of B has free admission into the upper part of the great cylinder A; but the upper part of each cylinder has no communication with its lower part.

From the bottom of the great cylinder proceeds the eduction-pipe K, having a valve at its opening into the cylinder; it then bends downward, and is connected with the conical condenser L. The condenser is fixed on a hollow box M, on which stand the pumps N and O, for extracting the air and water, which last runs along the trough T, into a cistern U, from which it is raised by the pump V, for recruiting the boiler, being already nearly boiling hot. Immediately under the condenser there is a spigot-valve, at S, over which is a small jet-pipe, reaching to the bend of the eduction-pipe K. The whole of the condensing apparatus is contained in a cistern, R, of cold water; a small pipe, P, comes from the side of the condenser, and terminates on the bottom of the trough T, and is there covered with a valve, Q, which is kept tight by the water that is always running over it.

Laftly, the pump-rods, X, caufe the outer end of the beam to preponderate, fo that the quiefcent pofition of the beam is that reprefented in the figure, the piftons being at the top of the cylinders.

Suppofe all the cocks open, and fteam coming in copioufly from the boiler, and no condenfation going on in L, the fteam muft drive out all the air, and at laft follow it through the valve Q. Now fhut the cocks *b* and *d*, and open the valve, S, of the condenfer; the condenfation will immediately commence, and draw off the fteam from the lower part of the great cylinder. There is now no preffure on the under fide of the pifton of the great cylinder A, and it immediately defcends. The communication, Y, between the lower part of the fmall cylinder B, and the upper part of the great cylinder A, being open, the fteam will go from the lower part of B, into the fpace left by the defcent of the pifton of A. It muft, therefore, expand, and its elafticity muft diminifh, and will no longer balance the preffure of the fteam coming from the boiler, and preffing above the pifton of B.

This pifton, therefore, if not withheld by the beam, would defcend till it came in equilibrio, from having fteam of equal denfity above and below it. But it cannot defcend fo faft; for the cylinder A is larger than B, and the arch of the beam, at which the great pifton is fufpended, is no longer than the arm which fupports the pifton of B; therefore, when the pifton of B has defcended as far as the beam will permit it, the fteam between the two piftons occupies a larger fpace than it did when both piftons were at the top of their cylinders, and its denfity diminifhes as its bulk increafes. The fteam beneath the fmall pifton is, therefore, not a balance for the fteam on the upper fide of the fame, and the pifton B will act to deprefs the beam with all the difference of thefe preffures.

The flighteft view of the fubject muft fhew the reader, that as the piftons defcend, the fteam that is between them will grow continually rarer and lefs elaftic, and that both piftons will draw the beam downwards. Suppofe now, that each one had reached the bottom of its cylinder, fhut the cock *a*, and the eduction-valve at the bottom of A, and open the cocks *b* and *d*. The communication being now eftablifhed between the upper and lower part of each cylinder, their piftons will be preffed equally on the upper and lower furfaces; in this fituation nothing, therefore, hinders the counter-weight from raifing the piftons to the top.

Suppofe them arrived at the top: the cylinder B is at this time filled with fteam of the ordinary denfity; and the cylinder A with an equal abfolute quantity of fteam, but expanded into a larger fpace. Shut the cocks *b* and *d*, and open the cock *a*, and the eduction-valve at the bottom of A; the condenfation will again operate, and caufe the piftons to defcend; and thus the operation may be repeated as long as fteam is fupplied; and once full of the cylinder B, of ordinary fteam, is expended during each working ftroke.

The cocks of this engine are compofed of two flat circular plates, ground very true to each other, and one of them turns round on a pin through their centres: each is pierced with three fectorial apertures, exactly correfponding with each other, and occupying a little lefs than one-half of their furfaces. By turning the moveable plate fo that the apertures coincide, a large paffage is opened for the fteam; and by turning it fo that the folid part of the one covers the aperture of the other, the cock is fhut. Such regulators are now very common in the caft-iron ftoves for warming rooms.

Mr. Hornblower's contrivance for making the collars for the pifton-rods air-tight, is thus; the collar is in fact two, placed at a fmall diftance from each other; and a fmall pipe, branching off from the fteam-pipe, communicates with the fpace between the collars. This fteam being a little ftronger than the preffure of the atmofphere, effectually prevents the air from penetrating through the upper collar; and though a little fteam fhould get through the lower collar into the cylinder A, it can do no harm. The manner of making this ftuffing-box is as follows: on the top of the cylinder is a box to contain fomething foft, yet pretty clofe, to embrace the pifton-rod in its motion up and down; and this is ufually a fort of plaited rope of white yarn, nicely laid in, and rammed down gently, occupying about a third of its depth; upon that is placed a fort of tripod, having a flat ring of brafs for its upper, and another for its lower part; and thefe rings are in breadth equal to the fpace between the pifton-rod and the fide of the box. This compound ring being put on over the end of the pifton-rod, another quantity of this rope is to be put upon it, and gently rammed as before; then there is a hollow fpace left between thefe two packings, and that fpace is to be fupplied with ftrong fteam from the boiler. Thus is the packing about the pifton-rod kept in fuch a ftate as to prevent the air from entering the cylinder when at any time there may be a partial vacuum above the pifton.

Mr. Hornblower's defcription of this engine was followed by a mathematical inveftigation of the principles of its action, by the ingenious profeffor Robifon, which demonftrates that it is the fame thing in effect as Mr. Watt's expanfion-engine; but though this is true, there is a confiderable difference in the fteps by which the effect is attained, which gives an important advantage when it is reduced to practice. We fhall give an inveftigation in a more popular form, ufing only common arithmetic. Mr. Hornblower affumed, that the power or preffure of fteam is inverfely as the fpace into which the fteam is expanded: this is the cafe with air, and for the prefent we will grant it to be fo with fteam, and reafon from the fame data as the ingenious inventor gives us.

To explain clearly what paffes in the two cylinders, we muft deviate from the precife form of the engine, and diveft ourfelves of one complication of ideas, by reducing both cylinders to the fame ftroke; therefore, fuppofe the engine to be made like *fig.* 2, which reprefents the two cylinders placed one upon the other, the lower one being double the capacity of the upper one, and both piftons being attached to the fame rod, which may be applied to the end of the beam, fo that the defcent of the piftons muft draw up the load at the oppofite end of the beam.

Then, if we fuppofe the fmall pifton to be 10 inches in diameter, the great pifton muft be 14.14 inches; and to avoid all difficulties of the ratio of the expanfion, and the preffure of fteam, we will fuppofe the engine to be worked by the preffure of atmofpheric air inftead of fteam; and for the convenience of round numbers in our calculation, we will confider the preffure at only 10 lbs. *per* circular inch on the furface of the pifton.

The area of the fmall pifton will be 100 circular inches, and being affumed to move without friction, the preffure upon it will be $10 \times 100 = 1000$ lbs. The area of the great pifton is twice as much, or 200 circular inches, and the preffure 2000 lbs.

Suppofe both piftons to be at the top of their refpective cylinders; let the atmofpheric air be admitted to prefs freely upon the upper furface of the fmall pifton; and fup-

poſe the ſpace between the two piſtons filled with air of the ſame denſity, while there is a perfect vacuum made in the lower part of the great cylinder, beneath its piſton.

Under theſe circumſtances, the two piſtons will begin to deſcend with ſomething leſs than 2000 lbs. of load upon the outer end of the beam, becauſe there are 2000 lbs. of preſſure on the great piſton by the air contained in the ſpace between the two piſtons, bearing on the 200 inches of ſurface with a weight of 10 lbs. *per* inch; and beneath this piſton there is nothing to counteract the preſſure. At the ſame time, the ſmall piſton, having air of equal denſity above and below it, is in equilibrio.

This force would balance a load of 2000 lbs.; but ſuppoſe we diminiſh the load to 1900 lbs., then the piſtons will immediately begin to deſcend; but they will ſoon ſtop, becauſe the air between the two piſtons muſt expand itſelf, to fill the increaſing ſpace occaſioned by the equal deſcent of both piſtons in the cylinders, one of which is twice the area of the other; and as the air becomes rarer, its preſſure on the great piſton muſt diminiſh. Now as this ſame diminution occaſions the ſmall piſton to have a power of deſcent, we will firſt conſider the piſtons ſeparately, and then conjointly, in their power of deſcent, with which they draw down the beam.

Deſcending Power of the Great Piſton.	Lbs.	Deſcending Power of the Small Piſto	Lbs.	Combined Power of both Piſtons.	Lbs.
At firſt the power will be In conſequence of the preſſure of 10 lbs. *per* circular inch upon its upper ſurface, and no preſſure beneath.	2000	At firſt the power will be - Becauſe the piſton is in equilibrio, having 1000 lbs. preſſing upwards, and 1000 lbs. downwards.	0	At firſt	2000
At one-fourth of the deſcent, the power will have diminiſhed, by regular decrements, to Becauſe the air between the two piſtons muſt occupy three-fourths of the ſmall cylinder, and one-fourth of the great cylinder, which is a ſpace equal to one and one-fourth of the original ſpace which it filled; therefore the ſpaces will be as five to four; and if the denſity of air is as the inverſe proportion of the ſpace which it occupies, the preſſure on the great piſton muſt be as four to five, or $\frac{4}{5}$ths of 2000 = 1600.	1600	At one-fourth, the power will be Becauſe the equilibrium does not continue, and at one fourth of the deſcent the preſſure beneath the ſmall piſton is reduced by the expanſion of the air between the two piſtons to four-fifths of 1000 = 800 lbs., while the preſſure above the piſton continues to be 1000. The power is, therefore, 1000 − 800 = 200.	200	At one-fourth -	1800
At one-half of the deſcent, the power will have diminiſhed to Becauſe at this poſition the air between the piſtons occupies one-half of the ſmall cylinder and one-half of the great one, which is a ſpace equal to one and one-half of the ſpace it filled originally. The ſpaces will therefore be as ſix to four, and the preſſure on the great piſton as four to ſix, or $\frac{2}{3}$ds of 2000 = $1333\frac{1}{3}$.	$1333\frac{1}{3}$	At one-half of the deſcent, the power will have increaſed to Becauſe the preſſure beneath is diminiſhed by the increaſed rarity of the air to $\frac{2}{3}$ds of 1000 = $666\frac{2}{3}$, while the downward preſſure continues to be 1000. The power is therefore 1000 — $666\frac{2}{3}$ = $331\frac{1}{3}$.	$333\frac{1}{3}$	At one-half	$1666\frac{2}{3}$
At three-fourths of the deſcent, the power will be only Becauſe the air muſt now occupy one-fourth of the ſmall cylinder, and three-fourths of the large cylinder, which is a ſpace equal to one and three-fourths of the original ſpace. Thus the ſpaces will be as ſeven to four, and the preſſure on the great piſton $\frac{4}{7}$ths of 2000 = $1142\frac{6}{7}$.	$1142\frac{6}{7}$	At three-fourths of the deſcent, the power will be - Becauſe the preſſure beneath is reduced by the rarity of the air to $\frac{4}{7}$ths of 1000 = $571\frac{3}{7}$, therefore the power is 1000 — $571\frac{3}{7}$ = $428\frac{4}{7}$.	$428\frac{4}{7}$	At three-fourths -	$1571\frac{3}{7}$
At the bottom of the cylinder, the power will be - Becauſe the air muſt occupy the whole of the large cylinder, a ſpace equal to twice the ſmall cylinder which it at firſt filled. The preſſure will therefore be $\frac{1}{2}$ of 2000.	1000	At the bottom, the power will be Becauſe the air beneath the piſton is reduced to one-half of its preſſure, or 500, which deducted from 1000, leaves 500.	500	At the bottom -	1500
Sum of the powers exerted by the great piſton in its deſcent	7076	Sum of the powers of the ſmall piſton - - - -	1461	Sum of the combined powers	

M

Now let us confider how Mr. Watt's principle of expanfion would operate in the fame circumftances; that is, in a cylinder of 14.14 inches diameter; which is to be fupplied with air of 10 lbs. preffure *per* circular inch, until it has completed one-half of its defcent, and leaving the remainder of the defcent to be accomplifhed by the expanfion of the air already contained in the upper half of the cylinder.

	Lbs.
At the beginning, the power of defcent will be	2000
At one-fourth, the power will ftill be -	2000
At one-half, the power will be - -	2000
At three-fourths of the defcent, the power will be diminifhed to - - - - -	$1333\frac{1}{3}$
Becaufe the air muft occupy one-fourth of the length of the cylinder, in addition to that half of the cylinder which it occupied before the expanfion began; therefore the fpace is one and a half times the former, or as three to two, and the preffure will be two-thirds of 2000.	
At the bottom the preffure will be - -	1000
Becaufe the air is expanded to occupy twice the fpace it filled before.	
	$8333\frac{1}{3}$

The fum total is very nearly the fame as the former, but both are greater than they fhould be, from the imperfect manner in which we have been obliged to make our calculation, fo as to exprefs it in common arithmetic, without having recourfe to fluxions, which is the only method of treating quantities that are conftantly increafing or decreafing by any given law.

The fource of the inaccuracy is eafily explained: at firft we fet out with the preffure at 2000 lbs. in Mr. Hornblower's engine, and did not take into the account that it decreafes at all, until the pifton has defcended to one-fourth, but reafoned as though it diminifhed all at once at that place; whereas it began to diminifh from the very firft ftarting. Here then we have taken a fmall quantity too much. In the fame manner, our procefs takes no notice of the diminution which happens between one-fourth and one-half of the defcent, or between the other points at which we have chofen to examine it; the refult is, as if the diminution took place fuddenly at each of thofe points. The remedy for this would have been to have taken the account at a greater number of places, as it is by fluxions alone that we can take an infinite number, fo as to obtain a true refult. Now in the fecond calculation of Mr. Watt's expanfion-engine, we have taken a ftill lefs number of fteps for the confideration of the expanfion, becaufe, although there are four fteps in the procefs, two of them are before the expanfion begins.

This is the reafon of the apparent difference; for in reality there is none in the fum total of the varying powers exerted through the whole ftroke, as will appear to any perfon who will take the trouble to read profeffor Robifon's inveftigation. But if we confider the difference of the manner in which the whole power is expended during the ftroke, we fhall fee great reafon to prefer Mr. Hornblower's method, from the much greater uniformity of the action; it begins at 2000, and ends at 1500; whilft Mr. Watt's begins at 2000, and ends at 1000: hence the neceffity of thofe ingenious contrivances for equalizing the action in Mr. Watt's patent of 1782. Mr. Hornblower's is not uniform, but approaches uniformity more nearly, fo that he could have carried the effect of the expanfive principle much farther, in employing ftronger fteam, than we believe he ever propofed to do.

We have been thus full upon this fubject, becaufe the gaining more power by the expanfion of air or fteam acting in double cylinders, has been a favourite idea with many, and there are no lefs than five different patents for it, but feveral of thefe have been upon miftaken notions; neither Mr. Watt's nor Mr. Hornblower's can have any advantage from fhutting off the air, or from a double cylinder, when air is ufed to prefs the pifton; nor could they derive any advantage from the expanfion of fteam in their engines, if the preffure of it was inverfely as the fpace it occupies.

The advantage of the expanfive principle arifes wholly from a peculiar property of fteam, by which, when fuffered to expand itfelf to fill a greater fpace, it decreafes in preffure or elaftic force by a certain law, which is not fully laid down; that is, the relation between its expanfive force and the fpace which it occupies is not clearly decided: but Mr. Woolf has found that, by applying thefe properties in their fulleft extent to the double cylinder engine, he can make moft important improvements in the effects which can be obtained from any given quantity of fuel. Steam is a fluid fo different from air, as to have no one property in common with it, except elafticity. This elafticity is wholly derived from the quantity of heat which it contains, and its force increafes and diminifhes with the quantity of heat; but by what law it increafes or diminifhes we are uncertain, becaufe we have no meafure of the actual quantity of heat which is contained in fteam of any given elaftic force. All we know with certainty is what is ftated in our table of expanfion, *viz.* that water, being converted into fteam, and confined in a clofe veffel, when heated until the thermometer indicates a certain temperature, will have a certain preffure or elaftic force. But here we muft obferve, that the thermometer indicates only the intenfity of the heat, without affording a direct meafure of its quantity. When fteam is fuffered to expand itfelf into any given fpace, the quantity of rarefied water which will be found to be contained in any given bulk of fteam, in its expanded ftate, muft be undoubtedly proportioned to the quantity of water contained in the fame bulk of the fteam, before the expanfion took place, in the inverfe ratio of the fpace which it originally occupied, and that fpace which it fills when expanded; but we cannot fay that this is the cafe with heat; and it is the quantity of heat alone which determines the elaftic force.

We believe that in practice Mr. Hornblower was not able to obtain any greater effect from the application of the expanfive action in two cylinders, than Mr. Watt did in one cylinder. In 1791-2, he erected an engine in Cornwall, at Tin-Croft mine, of which the large cylinder was 27 inches diameter, and worked with a ftroke of eight feet long, and the fmall cylinder 21 inches diameter, working with a fix-feet ftroke. The only account we have been able to obtain of the performance of this engine, is from a pamphlet publifhed by Thomas Wilfon, an agent of Meffrs. Boulton and Watt, profeffedly with a view to prevent the introduction of Mr. Hornblower's engines into that country, in which he makes it appear, that it raifed only 14,222,120 lbs. of water one foot high with each bufhel of coals.

In Mr. Hornblower's own account of his engine, in Gregory's Mechanics, he informs us, that "an engine was erected in the vicinity of Bath, fome years fince, on this principle, and under very difadvantageous circumftances. The engine had its cylinders 19 inches and 24 inches diameter, with lengths of ftroke in each fuitable to the occafion: *viz.* 6 feet and 8 feet refpectively. The condenfing apparatus was very bad, through a fear of infringement on Mr. Watt's patent; and the greateft degree

of vacuum which could be obtained, was no more than 27 inches of mercury. The engine worked four lifts of pumps to the depth of 576 feet, 4500 lbs. 14 strokes in a minute, 6 feet each, with a cylinder 6 feet long, and 19 inches diameter, with a great deal of inertia and friction in the rods and buckets; some of the latter of which were not more than 3½ inches diameter: and this it did, under all these disadvantageous circumstances, with 70 lbs. of coal (light coal) *per* hour."

To reduce this to the standard of one foot high, we must put the load 4500 lbs. × 6-feet stroke = 27,000 lbs. which the engine raised one foot high at every stroke; 27,000 lbs. × 14 strokes *per* minute = 378,000 lbs. raised one foot high each minute; 378,000 lbs. × 60 = 22,680,000 lbs. raised one foot high *per* hour, or with 70 lbs. of coals. As the coals are stated to be light, we will take them at only 84 lbs. *per* bushel, instead of 88 lbs., as Mr. Smeaton did, and say as 70 lbs. : 22,680,000 lbs. :: 84 lbs. : 27,216,000 lbs. of water raised one foot high with a bushel of coals, which is a very good performance, but not greater than Mr. Watt's.

In this engine, Mr. Hornblower says that two remarkable circumstances presented themselves to shew the advantages of this application of the principle: the one was, that the man who attended the engine would sometimes detach the smaller cylinder from the beam, and work only with the large one, and then the boiler would scarcely raise steam enough to keep the engine going; but no sooner was the small cylinder-rod attached to the beam, than the engine resumed its wonted activity, and the steam would blow up the safety-valve.

The next circumstance is, that when the detent, which kept the exhausting-valve shut, happened to miss its action, the piston would be checked, as it were, not being permitted to rise through the whole of the returning stroke; and it would, as by an instructive nature, come down again and again, until the detent performed its office, which is a practical argument for the power of the engine at the termination of its stroke.

In 1792, Mr. Hornblower made application to parliament for an extension of the term of his patent, but it was not granted: and he was prosecuted by Messrs. Boulton and Watt for infringement on their patent in using the condenser and air-pump. We believe none of these engines have been erected since the expiration of Mr. Watt's patent in 1800, until Mr. Woolf took up the subject of double-cylinder engines.

Mr. Woolf's Double-Cylinder Expansion-Engine.—In 1804 Mr. Arthur Woolf had a patent for improvements in steam-engines. The specification of his invention states, that he has ascertained by actual experiment, and reduced to practice, the following particulars respecting the expansibility of steam. That, in practice it is found that steam, acting with the expansive force of four pounds pressure *per* square inch against a safety-valve exposed to the atmosphere, is capable of expanding itself to four times the volume it then occupies, and still to be equal to the pressure of the atmosphere: that, in like manner, steam of the force of five pounds the square inch, can expand itself to five times its volume; and that masses or quantities of steam of the like expansive force of six, seven, eight, nine, or ten pounds pressure *per* square inch, can expand to six, seven, eight, nine, or ten times their volume, and still be respectively equal to the atmosphere, or capable of producing a sufficient action against the piston of a steam-engine, to cause the same to rise in the atmospheric engine of Newcomen with a counterpoise, or to be carried into the vacuous part of the cylinder of the improved engine, first brought into effect by Mr. Watt: that this ratio is progressive, and nearly, if not entirely, uniform; so that steam pressing with the expansive force of 20, 30, 40, or 50 pounds the square inch against a common safety-valve, will expand itself to 20, 30, 40, or 50 times its volume; and that, generally, as to all the intermediate or higher degrees of elastic force, the number of times which steam of any temperature and force can expand itself, is nearly the same as the number of pounds it is able to sustain on a square inch exposed to the common atmospheric counter-pressure; provided always, that the space, place, or vessel, in which it is allowed to expand itself, be kept at the same temperature as that of the steam, before it is allowed room to expand.

Respecting the different degrees of temperature required to bring steam to, and maintain it at, different expansive forces above the weight of the atmosphere, Mr. Woolf states that he has found by actual experiment, setting out from the boiling point of water, or 212° of Fahrenheit, at which degree steam of water is only equal to the pressure of the atmosphere; that, in order to give an increased elastic force equal to five pounds on each square inch, the temperature must be raised to about 227½°, when it will have acquired a power to expand itself to five times its volume, and still be equal to the atmosphere, and capable of being applied as such in the working of steam-engines, according to his invention. Various other pressures, temperatures, and expansive forces of steam, are shewn in the following table.

Woolf's Table of the relative Pressures *per* square Inch: the Temperature and Expansibility of Steam at Degrees of Heat above the boiling Point of Water, beginning with the Temperature of Steam of an elastic Force equal to five Pounds *per* square Inch; and extending to Steam able to sustain forty Pounds on the square Inch.

	Pounds *per* square Inch.		Degrees of Heat.			
Steam of an elastic force predominating over the pressure of the atmosphere upon a safety-valve		requires to be maintained by a temperature equal to about	227½	and, at these respective degrees of heat, steam can expand itself to about	5	times its volume, and continue equal in elasticity to the pressure of the atmosphere.
			230¼		6	
	7		232¾		7	
	8		235¼		8	
	9		237½		9	
	10		239½		10	
	15		250½		15	
	20		259½		20	
	25		267		25	
	30		273		30	
	35		278		35	
	40		282		40	

And ſo in like manner, by ſmall additions of temperature, an expanſive power may be given to ſteam to enable it to expand to 50, 60, 70, 80, 90, 100, 200, 300, or more times its volume, without any limitation but what is impoſed by the frangible nature of every material of which boilers and other parts of ſteam-engines can be made. And prudence dictates, that the expanſive force ſhould never be carried to the utmoſt which the materials can bear, but rather be kept conſiderably within that limit.

Having thus explained the nature of his diſcovery, Mr. Woolf proceeds to give a deſcription of his improvements grounded thereon.

If the engine is conſtructed originally with the intention of adopting theſe improvements, it ought to have two ſteam-cylinders of different dimenſions, and proportioned to each other, according to the temperature, or the expanſive force determined to be communicated to the ſteam made uſe of in working the engine; for the ſmaller ſteam-veſſel or cylinder muſt be a guide for the larger. For example; if ſteam of forty pounds the ſquare inch is fixed on, then the ſmaller cylinder ſhould be at leaſt one-fortieth part the contents of the larger one. Each cylinder ſhould be furniſhed with a piſton, and the ſmaller cylinder ſhould have a communication, both at its top and bottom, (top and bottom being here employed merely as relative terms, for the cylinders may be worked in a horizontal, or any other required poſition, as well as vertical,) with the boiler which ſupplies the ſteam; and the communications, by means of cocks or valves of any conſtruction adapted to the uſe, are to be alternately opened and ſhut during the working of the engine. The top of the ſmall cylinder ſhould have a communication with the bottom of the larger cylinder, and the bottom of the ſmaller one with the top of the larger, with proper means to open and ſhut theſe alternately by cocks, valves, or any other well-known contrivance. And both the top and bottom of the larger cylinder ſhould, while the engine is at work, communicate alternately with a condenſing veſſel, into which a jet of water is admitted to haſten the condenſation; or the condenſing veſſel may be cooled by any other means calculated to produce that effect.

Things being thus arranged, when the engine is ſet to work, ſteam of a high temperature is admitted from the boiler to act by its elaſtic force on one ſide of the ſmaller piſton, while the ſteam which had laſt moved it has a communication with the larger ſteam-veſſel or cylinder, where it follows the larger piſton, now moving towards that end of its cylinder which is open to the condenſing veſſel. Let both piſtons end their ſtroke at one time, and let us now ſuppoſe them both at the top of their reſpective cylinders, ready to deſcend; then the ſteam of forty pounds the ſquare inch, entering above the ſmaller piſton, will carry it downwards; while the ſteam below it, inſtead of being allowed to eſcape into the atmoſphere, or applied to any other purpoſe, will paſs into the larger cylinder above its piſton, which will make its downward ſtroke at the ſame time that the piſton of the ſmaller cylinder is doing the ſame thing; and while this goes on, the ſteam which laſt filled the larger cylinder in the upward ſtroke of the engine will be paſſing into the condenſer, to be condenſed during the downward ſtroke. When the piſtons in the ſmaller and larger cylinder have thus been made to deſcend to the bottom of their reſpective cylinders, then the ſteam from the boiler is to be ſhut off from the top, and admitted to the bottom of the ſmaller cylinder. The communication between the bottom of the ſmaller and the top of the larger cylinder is alſo to be cut off; and the communication is to be opened between the top of the ſmaller and the bottom of the larger cylinder. The communication between the bottom of the larger cylinder and the condenſer is to be cut off, and the ſteam which, in the downward ſtroke of the engine, filled the upper part of the larger cylinder, ſuffered to flow off to the condenſer. The engine will then make its upward ſtroke from the preſſure of the ſteam in the top of the ſmall cylinder, acting beneath the piſton of the great cylinder, and ſo on alternately, admitting the ſteam to the different ſides of the ſmaller piſton, while the ſteam laſt admitted into the ſmaller cylinder paſſes alternately to the different ſides of the larger piſton in the larger cylinders; the top and bottom of which are at the ſame time made to communicate alternately with the condenſer.

In an engine working in the manner juſt deſcribed, while the ſteam is admitted on one ſide of the piſton into the ſmaller cylinder, the ſteam on the other ſide has room made for its admiſſion into the larger cylinder, on one ſide of its piſton, by the condenſation taking place on the other ſide of the large piſton which is open to the condenſer; and that waſte of ſteam which takes place in engines worked only by the expanſive force of ſteam, from ſteam paſſing the piſton, is prevented; for all ſteam that paſſes the piſton in the ſmaller cylinder is received into the larger.

In ſuch an engine, where it may be more convenient for any particular purpoſe, the arrangement may be altered, and the top of the ſmaller made to communicate with the top of the larger cylinder; in which caſe the only difference will be, that when the piſton in the ſmaller cylinder deſcends, that in the larger will aſcend, and *vice verſâ;* which, on ſome occaſions, may be more convenient than to have the two piſtons moving in the ſame direction.

This engine is exactly the ſame in its action as Mr. Hornblower's, which we have before deſcribed. The novelty conſiſts in the application of ſteam of a high preſſure thereto, and in proportioning the capacities of the two cylinders to the expanſibility of the ſteam, according to his table. But Mr. W. goes on to ſtate, that effectual means muſt be uſed to keep up the requiſite temperature in all parts of the apparatus into which the ſteam is admitted, and in which it is not intended to be condenſed; and here it may be proper to ſtate, that inſtead of the uſual means of accompliſhing this, by incloſing them in the boiler, or in a ſteam-caſe communicating with the boiler, a ſeparate fire may with advantage be made under the ſteam-caſe containing the cylinders, which in that event will become a ſecond boiler, and muſt be furniſhed with a ſafety valve, to regulate the temperature. By means of the laſt-mentioned arrangement, the ſteam from the ſmaller cylinder or ſteam-meaſurer may be admitted into the larger cylinder, when kept at a higher temperature than the ſteam in the ſmaller cylinder, by which its power to expand itſelf may be increaſed; and, on the contrary, by keeping the larger cylinder at a lower temperature than the ſmaller, its expanſibility will be leſſened, which, on particular occaſions, and for particular purpoſes, may be deſirable. In every caſe, care muſt be taken that the boiler, or caſe in which the cylinder is incloſed, the ſteam-pipes, and generally all the parts expoſed to the action of the expanſive force of the ſteam, ſhall have a ſtrength proportioned to the high preſſure to which they are to be expoſed.

It is not adviſable that the proportion of the capacity of the ſmaller cylinder or ſteam-meaſurer, to the capacity of the larger or working cylinder, ſhould in any caſe be ſmaller than the proportion of the expanſion of the ſteam which is to be uſed in it, as we have ſtated; yet in the making of it larger, conſiderable latitude may be allowed; for example, with ſteam of forty pounds the ſquare inch, a ſmall cylinder or meaſurer of one-twentieth, or even larger, inſtead of one of fortieth the capacity of the larger or working cylin-

der, and ſo with ſteam of any given ſtrength. And in many caſes, it may be adviſable that this ſhould be the caſe, becauſe of the difficulty of preventing ſome waſte of ſteam, or partial condenſation, which might leſſen the rate of working, if not allowed for in the ſize of the ſmall cylinder or ſteam-meaſurer.

In all caſes when the engine is ready for working, whatever may be the proportion that has been adopted, or intended to be worked with, it ſhould have its power tried by altering the load on the valve that aſcertains the force of the ſteam, in order that the ſtrength of ſteam beſt adapted for the engine may be aſcertained, for it may turn out to be advantageous, that the ſteam ſhould be employed in particular engines of an elaſtic force, ſomewhat over or under what was firſt intended.

Mr. Woolf alſo ſtates, that Mr. Watt's engines may be improved by the application of his diſcovery in making the boiler, and the ſteam-caſe in which the working cylinder is incloſed, much ſtronger than uſual, and by altering the ſtructure and dimenſions of the valves for admitting ſteam from the boiler into the cylinder in ſuch a manner, that the ſteam may be admitted very gradually by a progreſſive enlargement of the aperture, ſo as at firſt to wire-draw the ſteam, and afterwards to admit it more freely. The reaſon of this precaution is this, that ſteam of ſuch elaſtic force as Mr. Woolf propoſes to employ, if admitted ſuddenly into the cylinder, would ſtrike the piſton with a force that would endanger the ſafety and durability of the engine. The aperture allowed to the valve for admitting ſteam into the cylinder, or cylinders, ſhould be regulated by the following conſideration. If the intention is, that the engine ſhould work wholly, or almoſt wholly, by condenſation, the ſteam, in paſſing into the cylinder, ſhould be forced to wire-draw itſelf only ſo much, that the piſton may perform the whole, or a great part of the ſtroke, by the time that the intended quantity of ſteam has been admitted into the cylinder. For example, when ſteam of forty pounds on the ſquare inch is uſed, ſuch a quantity of it muſt be allowed to enter as ſhall be equal to one-fortieth of the capacity of the cylinder, and ſo in proportion when ſteam of any other force is employed; and when the requiſite quantity has been admitted, the ſteam is to be ſhut off till the proper moment for admitting a freſh quantity. But if it is intended that advantage ſhall alſo be taken of the elaſtic force of the ſteam acting on one ſide of the piſton, while condenſation goes on on the other ſide, then the ſteam muſt be admitted more freely, but ſtill with caution at firſt, for the reaſon already mentioned.

This latter is the ſame thing as Mr. Watt's expanſion-engine; but with the addition of gradually diminiſhing the aperture of the ſteam-valve as the piſton deſcends, inſtead of ſtopping it altogether at a certain portion of the deſcent, by which means the action of the engine is rendered more uniform. We think that, by regulating the deſcent of the valve by an accurate movement, a very good effect may be produced in this manner, without the complication of two cylinders or other parts; the only objection is, that if at any time the valve ſhould be fully opened by accident, the preſſure might ſuddenly become ſo great, from the ſtrong ſteam acting upon the full ſurface of the piſton, as to break the engine to pieces.

In 1805, Mr. Woolf took out a ſecond patent for further improvements, in which he propoſes, as before, to apply fire to the cylinder itſelf, to heat the ſteam after it is thrown into the working cylinder; and this was to be done by a fire being placed beneath the caſe containing the cylinder: the ſpace between the caſe and the cylinder was to be filled with oil, wax, fuſible metal, or mercury. He alſo propoſes a method of preventing the paſſage of any of the ſteam from that ſide of the piſton which is acted upon by the ſteam, to the other ſide, which is open to the condenſer. In thoſe ſteam-engines which act as double engines, he effects this by employing upon, or about the piſton, a column of mercury, or fluid metals, in an altitude equal to the preſſure of the ſteam. The efficacy of this arrangement will, he ſays, appear obvious, from attending to what takes place in the working ſuch a piſton. When the piſton is aſcending, that is, when the ſteam is admitted below it, the ſpace on its upper ſide being open to the condenſer, the ſteam, endeavouring to paſs up by the ſide of the piſton, is met, and effectually prevented by the column of metal, equal or ſuperior to it in preſſure; and during the down ſtroke no ſteam can poſſibly paſs without firſt forcing all the metal through.

In working what is called a ſingle engine, a leſs conſiderable altitude of metal is required, becauſe the ſteam always acts on the upper ſide of the piſton; and in this caſe, oil or wax, or fat of animals, or ſimilar ſubſtances in ſufficient quantities, will anſwer the purpoſe. But care muſt be taken, either in the double or ſingle engine, when working with this piſton, that the outlet which conveys the ſteam to the condenſer ſhall be ſo ſituated, and of ſuch a ſize, that the ſteam may paſs freely, without forcing before it, or carrying with it, any of the metal, or other ſubſtance employed, that may have paſſed by the piſton: and at the ſame time providing another exit for the metal, or other ſubſtance collected at the bottom of the cylinder to convey the ſame into a reſervoir kept at a proper heat, whence it is to be returned to the upper ſide of the piſton by a ſmall pump, worked by the engine, or by ſome other contrivance. In order that the fluid metal uſed with the piſton may not be oxydated, ſome oil or other fluid ſubſtance is always to be kept on its ſurface, to prevent its coming in contact with the ſteam: and to prevent the neceſſity of employing a large quantity of fluid metal, although the piſton muſt be as thick as the depth of the column required, the diameter need be only a little leſs than the ſteam-veſſel, or working cylinder, excepting where the packing, or other fitting, is neceſſary to be applied; ſo that, in fact, the column of fluid metal forms only a thin body round the piſton.

We have ſeen an engine of an eight-horſe power of this kind at work, with a fluid metal on the piſtons: it effectually prevented the leakage. But as it required to have the cylinders twice as long as uſual, in order to have ſufficient room for the long or thick piſtons which it required, and as theſe piſtons muſt be of conſiderable weight, the method is not at all applicable in practice; and, indeed, the increaſe of the bulk of the moving parts is ſuch as to counterbalance the advantage, which is confined to the ſaving of ſteam by leakage: for the friction muſt be greater than in another engine, becauſe the piſton muſt be packed as tight as uſual, to be able to ſuſtain a column of fluid metal, which muſt be more than equal in preſſure to that of the ſteam; and when the ſteam preſſes upon the piſton, the preſſure of the fluid metal to leak by the piſton muſt be double that of the ſteam: alſo, the friction of ſo great a ſurface of fluid metal preſſing againſt the inſide of the cylinder is very great.

In 1810, Mr. Woolf had a third patent, the object of which is to prevent the waſte of ſteam, from leakage by the piſton. For this purpoſe, he does not allow the ſteam to come to the piſton at all, but cauſes it to act in a different veſſel, and tranſmits the action thereof to the piſton by oil or fluid metal: thus, at the ſide of the

cylinder, he places a ſeparate veſſel, communicating with the lower part of the cylinder by a large pipe or paſſage from the bottom of each; then ſteam, being admitted into this veſſel, will preſs upon the ſurface of the oil or fluid metal contained in it, and force the ſame to paſs out of that veſſel into the cylinder, where it will act beneath the piſton to preſs the ſame upwards; a vacuum being at the ſame time made in the upper part of the cylinder, to give effect to the preſſure. The ſteam is then made to preſs upon the upper ſurface of the piſton, which is always covered with a quantity of the fluid; and at the ſame time a vacuum is made in the ſeparate veſſel, ſo as to relieve the ſurface thereof from all preſſure: in conſequence, the piſton is made to deſcend. It is evident that the piſton muſt be packed ſo tight as to ſuffer none of the fluid to paſs by it; but this is eaſy, in compariſon with the difficulty of making a packing ſufficiently tight to reſiſt the paſſage of ſteam, particularly when it is ſo rare as the expanded ſteam which Mr. Woolf ſometimes uſes in his engine. The ſeparate veſſel of which we have ſpoken, is in ſome caſes to be the jacket or ſpace which ſurrounds the cylinder, which is then to be open at bottom.

This contrivance is ingenious, but we think the neceſſity of an additional cylinder is an objection which will prevent its adoption in large engines; and for ſmall engines the advantages are not ſo great.

Performance of Mr. Woolf's Engines.—Since his firſt patent, Mr. Woolf has erected ſeveral ſmall engines, which performed well, and with an evident economy of fuel. But theſe engines being employed to turn mills, of which the operations do not afford ſo exact an eſtimate of the power as the operation of pumping water, Mr. Woolf's engines did not come to a direct and indiſputable compariſon with thoſe on Mr. Watt's principle, until 1815, when two large engines were ſet to work in Cornwall, at Wheal Vor and Wheal Abraham mines, for pumping water; and theſe have ſince been regularly reported in Meſſrs. T. and J. Leans reports, of which we have before ſpoken, and of which one of the objects was to aſcertain the comparative merit of the double and ſingle cylinder engines.

The report for May, 1815, ſtates the average performance of theſe two engines at 49,980,882 lbs. lifted one foot high for each buſhel of coals; and ſince that time they have done more than 50,000,000 lbs.

The engine at Wheal Vor has a great cylinder of 53 inches diameter, and 9-feet ſtroke; and the ſmall cylinder is about one-fifth of the contents of the great one. The engine works ſix pumps, which, at every ſtroke, raiſe a load of water of 37,982 lbs. weight 7½ feet high, which is the length of the ſtroke in the pumps. This makes a preſſure of 14.1 lbs. *per* ſquare inch on the ſurface of the great piſton, and it makes 7.6 ſtrokes *per* minute. With reſpect to its conſumption of coals, it raiſed, in March, 1816, 48,432,702 lbs. one foot high with each buſhel; April, 1816, 44,000,000 lbs.; May, 1816, 49,500,000 lbs.; and in June, 1816, 43,000,000 lbs.

From the ſame reports we learn, that the engine at Wheal Abraham mine has a great cylinder of 45 inches diameter, working with a 7-feet ſtroke, at the rate of 8.4 ſtrokes *per* minute, under a load of 24,050 lbs., which it raiſes 7 feet at each ſtroke. Its performance during the above four months was 50,000,000 lbs.; 50,908,000 lbs.; in May, 56,917,312 lbs., which, we believe, is the greateſt performance ever made by a ſteam-engine; and in June, 51,500,000 lbs.

We have before given a ſimilar account of Mr. Watt's engines; but at the ſame time we muſt obſerve, that the variation in the performance of different ſteam-engines, which are conſtructed upon the ſame principle, and working under the ſame advantages, is the ſame as would be found in the produce of the labour of ſo many different horſes, or other animals, when compared with their conſumptive food; for the effects of different ſteam-engines will vary as much from ſmall differences in the proportions of their parts, as the ſtrength of animals from the vigour of their conſtitution: and, again, there will be as great differences in the performance of the ſame engine, when in bad or good order, from all the parts being tight and well oiled, ſo as to move with little friction, as there is in the labour of an animal, from his being in good or bad health, or exceſſively fatigued; but, in all caſes, there will be a maximum which cannot be exceeded, and an average which we ought always expect to attain.

Plate V. *fig.* 3. is a ſketch to ſhew the arrangement of the valves and cylinders of theſe two engines: A is the large cylinder, and B the little cylinder, each incloſed in its ſteam-caſe. The ſteam is admitted from the boiler into the ſteam-caſe of the large cylinder A, by a communication at C; and there is a communication between this ſteam-caſe and that of the ſmall cylinder; ſo that all the ſteam for the ſupply of the engine paſſes through both of the ſteam-caſes, which therefore become part of the communication between the boiler and the little cylinder, into which the ſteam is firſt admitted. D furniſhes a communication for carrying back to the boiler any water which may be produced by condenſation in the ſteam-caſe, before the engine is heated to the proper temperature. E is the pipe from the ſteam-caſe to ſupply the engine; it has a regulating-valve. F is the valve-box of the ſmall cylinder, the ſpindle of the one valve working through that of the other; and the paſſage for the ſteam from the caſe into the ſmall cylinder is ſituated between the two valves. G is the valve that opens the communication between the bottom of the ſmall cylinder B, and the top of the large cylinder A, when the piſton thereof is to be preſſed down. H is the valve that returns the ſteam from above to below the large piſton, when the piſton is to aſcend. And I is the exhauſtion-valve, to carry off the ſteam to the condenſer.

When the engine makes its down-ſtroke, the upper valve at F is opened, and admits the ſteam from the caſe to preſs upon the ſmall piſton, the valve G being opened at the ſame time, which ſuffers the ſteam to paſs from the under ſide of the ſmall to the upper ſide of the large piſton; and the valve I is opened to make a paſſage from beneath the great piſton to the condenſer. Theſe three upper valves, F, G, I, open at the ſame inſtant of time.

When both piſtons arrive at the bottom of their reſpective cylinders, theſe three valves are ſhut all together, and the lower ſteam-valve at F is opened, to return the ſteam from above to below the ſmall piſton; the valve H doing the ſame to the large cylinder, and both piſtons return in equilibrio by the counter-weight; but the upper valve at F can be ſhut off at any part of the ſtroke, according to the load of the engine.

Thoſe who are converſant with ſteam-engines will perceive, from the paſſing of the ſteam, as above deſcribed, from the upper to the lower ſide of each of the piſtons reſpectively, that the engines at Wheal Vor, and at Wheal Abraham, are at preſent working with a ſingle ſtroke. Were theſe engines working double, the ſteam would, on the down-ſtroke, be made to paſs, the ſame as before deſcribed, from the under ſide of the ſmall, to the upper ſide of the large piſton, ſteam from the boiler in the mean time coming in upon the ſmall piſton, and the under ſide of the large piſton being open to the

condenſer; but on the up-ſtroke, the action would be different from what we have deſcribed, for the ſteam would paſs from the top of the ſmall cylinder to beneath the large piſton, while ſteam would be admitted from the boiler under the ſmall piſton, the top of the large cylinder being open to the condenſer.

Mr. Woolf's Boiler for raiſing Steam of a high Preſſure with Safety.—The boilers which Mr. Woolf employs in his engines are different from thoſe of other engines which work with ſteam of a low preſſure, the water being contained in ſeveral cylindrical tubes of caſt-iron, which are filled with water, and expoſed to the flame nearly in an horizontal poſition.

Mr. Woolf has a patent for this boiler, which the ſpecification ſtates to conſiſt of two or more cylindrical veſſels, properly connected together, and ſo diſpoſed, as to conſtitute a ſtrong and fit receptacle for the water intended to be converted into ſteam of a temperature and under a preſſure uncommonly high, and alſo to preſent an extenſive portion of convex ſurface to the current of flame and heated air from a fire; likewiſe of other large cylindrical receptacles placed above the former cylinders, and properly connected with them, for the purpoſe of containing ſome water and the ſteam.

Theſe cylindrical veſſels are ſet in a furnace ſo adapted to them, as to cauſe the greater part of the ſurface of each of them, or as much of the ſurface as may be convenient, to receive the direct action of the fire, or heated air or flame.

Plate V. *figs.* 4 and 5, repreſents one of theſe boilers in its moſt ſimple form. It conſiſts of eight tubes, marked *a*, made of caſt-iron, or any other fit metal, which are each connected with the larger cylinder A, placed above them, as is ſhewn in the ſide view, *fig.* 5, in which the ſame letters refer to the ſame parts as in *fig.* 4. In *fig.* 5. is alſo ſhewn the manner in which the fire is made to act. The fuel reſts on the grate-bars at B, and the flame and heated air, being reverberated from the part above the two firſt ſmaller cylinders, go under the third, over the fourth, under the fifth, over the ſixth, under the ſeventh, and partly over and partly under the eighth ſmall cylindric tube, all which tubes are full of water. The direction of the flame, until it reaches the laſt-mentioned tube, is ſhewn by the dotted curved lines and arrows. When it has reached that end of the furnace, it is carried by the flue, O, to the other ſide of a wall, built beneath the main cylinder A, in the direction of its length, and the flame then returns under the oppoſite end of the ſeventh ſmaller cylinder over the ſixth, under the fifth, over the fourth, under the third, over the ſecond, and partly over and partly under the firſt, when it paſſes into the chimney. The wall before-mentioned, which divides the furnace longitudinally, anſwers the double purpoſe of lengthening the courſe which the flame and heated air have to traverſe, giving off heat to the boiler in the paſſage, and alſo of ſecuring the flanges, or other joinings, employed to unite the ſmaller tubes to the main cylinder, from being injured by the fire. The ends of the ſmall cylindric tubes reſt on the brick-work which forms the ſides of the furnace, and one end of each of them is furniſhed with a cover, ſecured in its place by ſcrews and a flanch, but which can be taken off at pleaſure, to allow the tubes to be cleared, from time to time, from any incruſtation or ſediment which may be depoſited in them.

To any convenient part of the main cylinder, A, a tube is affixed, to convey the ſteam to the ſteam-engine. In working with ſuch boilers, the water carried off by evaporation is replaced by water forced in by the uſual means of a high-preſſure boiler, that is, a forcing-pump; and the ſteam generated is carried to the place intended by means of pipes connected with the upper part of the cylinder A. In the ſpecification, means are pointed out for applying this plan to the boilers of ſteam-engines already in uſe, by ranging a row of cylinders beneath the preſent boiler, and connecting them with each other, and with the boiler. Directions are alſo given for conſtructing boilers compoſed of cylinders diſpoſed vertically. In every caſe the tubes compoſing the boiler ſhould be ſo combined and arranged, and the furnace ſo conſtructed, as to make the fire and flame act around and over the tubes, ſo as to embrace the largeſt poſſible quantity of their ſurface. It muſt be obvious to any one, that the tubes may be made of any kind of metal; but caſt-iron is the moſt convenient. The ſize of the tubes may be varied; but in every caſe, care ſhould be taken not to make the diameter too great: for it muſt be remembered, that the larger the diameter of any ſingle tube is in ſuch a boiler, the ſtronger it muſt be made in proportion, to enable it to bear the ſame expanſive force of ſteam as the ſmaller cylinders. It is not eſſential, however, to the invention, that the tubes ſhould be of different ſizes; but the upper cylinders, eſpecially the one which is called the ſteam-cylinder, ſhould be larger than the lower ones, it being the reſervoir, as it were, into which the lower ones ſend the ſteam, to be thence conveyed away by the ſteam-pipe. The following general directions are given reſpecting the quantity of water to be kept in a boiler of this conſtruction; *viz.* it ought always to fill, not only the whole of the lower tubes, but alſo the great ſteam-cylinder A, to about half its diameter, that is, as high as the fire is allowed to reach; and in no caſe ſhould it be allowed to get ſo low, as not to keep the vertical necks, or branches, which join the ſmaller cylinders to the great cylinder, full of water, for the fire is only beneficially employed when applied, through the medium of the interpoſed metal, to water, to convert it into ſteam; that is, the purpoſe of the boiler would in ſome meaſure be defeated, if any of the parts of the tubes which are expoſed to the direct action of the fire, ſhould preſent a ſurface of ſteam in their interior, inſtead of water, to receive the tranſmitted heat. This muſt, more or leſs, be the caſe, whenever the lower tubes, and even a part of the upper, are not kept filled with the water.

Reſpecting the furnace for this kind of boiler, it ſhould always be ſo built as to give a long and waving courſe to the flame and heated air, forcing them the more effectually to ſtrike againſt the ſides of the tubes which compoſe the boiler, and ſo to give out the greateſt poſſible portion of their heat before they reach the chimney. Unleſs this be attended to, there will be a much greater waſte of fuel than neceſſary, and the heat communicated to the contents of the boiler will be leſs from a given quantity of fuel.

When very high temperatures are not to be employed, the kind of boiler juſt deſcribed is found to anſwer very well; but where the utmoſt force of the fire is deſirable for producing the moſt elaſtic ſteam, the parts are combined in a manner ſomewhat different, though the principle is the ſame. In the Philoſophical Magazine, vol. xvii. p. 40, are a deſcription and drawing of a boiler of this kind, two of which were erected in 1803 at Meſſrs. Meux's brewery.

In every caſe Mr. Woolf uſes two ſafety-valves, at leaſt, in his apparatus, to prevent accidents; a precaution which cannot be too ſtrongly enforced, as it may happen, when

but one is employed, that by ſome accident it may get locked, and the engine and people about it be expoſed to the danger of an exploſion.

In thoſe engines of Mr. Woolf's which we have ſeen, he employs boilers like the one deſcribed, *viz.* with two ſmall tubes beneath, which are full of water, and expoſed to the immediate action of the flame, communicating by perpendicular necks or branches with the large cylinder above, which has water in the lower part, and ſteam in the upper. The only difference from what we have above deſcribed is, that the lower and upper tubes are placed in the ſame direction, inſtead of being at right angles to each other; and the flame proceeds in the direction of their length, inſtead of croſſing them: the lower or water tubes are rather inclined upwards. The metal of theſe tubes is made very thick, with a view to ſtrength and durability.

The idea of making boilers for raiſing ſtrong ſteam, by a number of ſmall tubes, which can be made ſtronger than one large veſſel, is not original with Mr. Woolf; Mr. Blakey, of whom we have before ſpoken, having propoſed it in a ſmall tract which he publiſhed in French, at the Hague, in 1776. But his tubes were to be placed over each other, in an inclined direction; and the water being admitted at the upper end, ran down within the heated inclined tubes, and became converted into ſteam.

Woolf's Regulating Steam-Valve.—Beſides the common ſafety-valves, Mr. Woolf has alſo introduced a valve of a new conſtruction into the ſteam-pipe itſelf, to regulate the quantity that ſhall paſs from the boiler. In fact, it is a ſelf-acting ſteam-regulator, and extremely ingenious. A (*fig.* 6.) is a part of the great or ſteam cylinder of one of Mr. Woolf's boilers; B B, the neck or outlet for the ſteam, ſurmounted by a ſteam-box C, which is joined to the neck B B, by the flanges *a, a.* The top or cover of the ſteam-box C, marked with the letter D, is well ſecured in its place, and has a hole through it for the rod of the valve to paſs; and the interior of the hole is formed to a box to hold a ſtuffing, and make the rod work up and down ſteam-tight; the ſtuffing being kept in its place by means of a collar, ſcrewed down in the uſual way, as ſhewn in the figure. By means of a pin *b*, and the two vertical pieces *e, e*, the ſliding-valve rod is made faſt to *m*, which is a cloſe cover to the hollow cylinder *n n*. The cover, *m*, fits ſteam-tight into the conical ſeat, at the upper end of a collar *o o*, which is made faſt to the flange *a a*, and deſcends into the neck of the boiler, forming a barrel, in which the cylinder fits cloſe. The cylinder, *n n*, is open at bottom, having a free communication with the ſteam in the boiler A; and it has three vertical ſlits cut through the ſides, one of which, S, is ſhewn in the plate. The ſum of the area of all theſe ſlits or openings is equal to the area of the opening of the ſeat or collar *o o*, in which the cylinder, *n n*, works.

When the ſteam acquires a ſufficient degree of elaſtic force to raiſe the valve, (that is, the cylinder *n n*, with its cover *m*, and the rod R,) together with whatever weight the rod may be loaded, then the openings S, riſing above the ſteam-tight collar or ſeat *o o*, allow the ſteam to paſs into the ſteam-box C, and to flow off to the engine through the pipe N. But the quantity of ſteam that paſſes is proportioned to the elaſtic force it has acquired, and the weight with which the valve is loaded; becauſe the riſe of the openings, S, above the collar *o o*, will be in that proportion.

This valve may be loaded by applying weights in any of the uſual methods; but Mr. Woolf prefers the one ſhewn in the drawing, in which the upper part of the rod, R, is joined by means of a chain to a quadrant of a circle Q, with an arm projecting from it, as repreſented in the plate, for the purpoſe of carrying a pendulum weight Z, that admits of being moved nearer to or farther from the centre of the quadrant, according as the preſſure of the valve is wiſhed to be increaſed or diminiſhed.

As the valve riſes, the weight moves upwards in the arc *n n*, giving a continually increaſed reſiſtance to the farther riſing of the valve, proportioned to the horizontal diſtance of the weight from the centre of Q, of which the weight attains a continual increaſe by its riſe in the arc, according to the horizontal diſtances meaſured on the line Q *p*, paſſing through the centre of the weight by perpendiculars from the horizontal line.

Thus, if the weight Z preſſes down the valve *m*, with a force equal to 20 lbs. on the ſquare inch of the aperture in *o o*, in its preſent poſition, when it riſes to the poſition at *i*, it will preſs with a force equal to 30 lbs.; and at *p*, with a force equal to 40 lbs. on the ſquare inch; ſo that the rod, Z, may be made to ſerve at the ſame time as an index to the perſon who attends the fire, nothing more being neceſſary for this purpoſe than to graduate the arc deſcribed by the end of the rod Q Z, by experimental trials. In the ſide of the ſteam-box C, there is an opening N, to allow the ſteam to paſs from it by a pipe to the ſteam-engine.

It is plain that the adjuſtment of the poſitive preſſure on this valve can be determined by ſliding the weight, Z, of the pendulum to a greater or leſs diſtance from the centre of motion. Again, to adjuſt the rate of the increaſing forces, ſo as to correſpond with the increaſing force of the ſteam, the radius of the quadrant, Q, muſt be apportioned to the diameter of the valve, and the opening of the ſlits S, ſo that the aſcent of the weight, Z, in its quadrant will be correſpondent to the varying preſſure. This adjuſtment muſt be made as nearly as it can be done before the valve is fixed; and to bring it afterwards to an exact regulation, the chain is attached to the rod, R, by a nut and ſcrew; by means of which, any part of the arc can be uſed that is found moſt correſpondent with the varying preſſure, becauſe the rate at which the reſiſtance of the lever increaſes is more rapid when the pendulum is near to the perpendicular, than when it approaches the horizontal poſition.

The ſame effect may be produced, by making the ſlits in the ſide of the cylinder narrower at the lower part of the cylinder, inſtead of being parallel.

Edelcrantz's Safety-Valve.—The chevalier Edelcrantz contrived a ſafety-valve, ſome years ago, which has the ſame properties as Mr. Woolf's, and is worthy of notice, as being more ſimple in its conſtruction. A ſmall braſs cylinder is fixed on the boiler, and fitted with a piſton, which moves with very little friction, in order that it may deſcend by its own weight, after it has been raiſed up, without, however, permitting the ſteam to paſs between it and the cylinder in any quantity. The lower part of the cylinder communicates with the boiler, and the upper part is cloſed by a ſmall cover ſcrewed on to it, and perforated with a hole, through which the piſton-rod paſſes eaſily. This cover ſerves the double purpoſe of guiding the rod, and preventing the piſton from being blown out. The piſton-rod is furniſhed with a ſhoulder, which ſerves to ſupport different weights which are placed upon it, and they can be changed at pleaſure. The ſide of the cylinder is pierced with holes opening to the air: the holes are very ſmall, and placed above each other at the diſtance of about a line; but

this distance, as well as the number of them, is a matter of indifference.

To give an idea of the effect of this small apparatus, let us suppose the piston lowered, and loaded with any weight, and that a fire is kindled under the boiler. When the vapour has acquired sufficient elasticity to raise the weights, the piston will ascend; and having passed the first hole, some vapour will escape.

If this aperture be of sufficient size for the passage of the quantity of vapour continually produced, the piston will remain there stationary, and in a state of oscillation; if not, it will ascend above the second, third, &c. hole; and if the intensity of the fire is sufficiently strong, above the last, which must be made larger, that, by giving the proper means of escape to the vapour, all accidents may be prevented. It is here evident, that though the greater or less elevation of the piston, as well as the number of the holes open, depend on the variations and different intensities of the fire, these variations, however, have no influence on the interior heat, and the elasticity of the vapour contained in the digester, since their force is always proportioned to the weight with which the piston is loaded, and which is constant. This safety-piston seems likely to afford, for delicate experiments, greater exactness than the usual safety-valves hitherto employed, with levers charged with weights: for in the whole course of the space which the cylindric piston passes over in ascending, the state of the elasticity of the vapour is the same; whereas, when the conical valve in common use is once raised up, nothing indicates whether or how much the present state of the vapour surpasses the first effort it made to open the valve. Besides, the diameter of the piston being once known, the force of the vapour requisite for each experiment can be easily regulated and determined: if we suppose, for example, that the lower surface of the piston is $\frac{1}{16}$th of a square inch, each ounce of weight placed on the shoulder of the piston-rod will be equivalent to the pressure of a pound on each square inch of the surface, and so on in proportion. As this pressure then remains constant, the experiment will be more determinate, and consequently more comparative. The application of this piston to the boiler of the steam-engine needs no farther explanation, except that, in this case, the diameter of the piston must be considerably increased. It seems here to offer the same advantage of greater uniformity in the force of the steam, especially if the motion of the piston be employed to regulate the fire of the furnace, and to prevent the useless dispersion of the vapour, by preventing an excess in the intensity of the fire. The following apparatus may be used for this purpose. Let the aperture of the flue for the current of air which maintains the combustion of the fuel be provided with a register, which, by rising and falling, will open or shut that passage of air: if the motion of the safety-piston be combined by any means with the register, in such a manner that when the former ascends, the latter descends, so that when the piston is at its greatest elevation, the register shall be entirely shut, it is evident that since the heat produced depends on the access of the air, the elasticity of the vapour, being determined by the weight on the piston, will not only remain within the bounds prescribed for it, but will regulate itself, by preventing any more air from entering the furnace than is necessary to maintain its force. A figure, representing this useful apparatus more minutely, may be found in the 17th volume of the Philosophical Magazine, p. 162.

Before quitting the subject of double-cylinder engines, we shall notice some others beside those of Mr. Hornblower and Mr. Woolf.

Messrs. James and John Roberton had a patent for one in 1800. The professed object of the double cylinder was to save that portion of steam, which in the best constructed steam-engines escapes past the sides of the piston in the time of working, and is lost without producing any mechanical effect whatever. Mr. Roberton's intention was to prevent so great a quantity of steam from escaping, and in making the steam, which actually did escape, act on another piston, and add to the power of the engine. There are two steam-cylinders, with a piston fitted to each; the one cylinder of a smaller, and the other of a larger size. These two cylinders act together in producing the effect, and are furnished with a condensing vessel and air-pump, similar to other engines. The same patent contains the description of the smoke-burning furnace, which has been very extensively used.

Mr. William Deverell obtained a patent in 1805, for improvements in the steam-engine. He proposes to have two working cylinders, placed near to one another, each having a pipe of communication, with a large vessel, in which the steam, after passing from the small cylinder, is suffered to expand itself, before entering the large cylinder. The pistons in the two cylinders work alternately up and down by means of valves or cocks, opening and shutting as in the common engine. Suppose the small piston has just made a stroke, and a passage is opened to the steam-vessel at the end of the stroke; at first beginning to work the engine, the vessel will be full of steam of about 18lbs. pressure, admitted from the boiler, but afterwards will only be supplied by the steam thrown into it from the small cylinder. The vessel should be about twenty times larger in capacity than the smallest working cylinder; and the larger it is, the more regular will be the pressure on the great piston, which is worked by the steam coming from the steam-vessel. If the steam in the boiler be of 54lbs. pressure *per* square inch, the ratio of the two working cylinders may be as 1 to 3, for then the smaller one will supply the larger with steam of about 18lbs. pressure: the proportion, however, may be varied, though these are thought best by the patentee. The improvements here are represented to consist in the steam going from the smaller working cylinder to the steam-vessel, and then from the steam-vessel to the larger working cylinder, from which it is afterwards drawn off, and condensed. By these means the engine will be very regular in its operations. Suppose the steam in the boiler is at 54lbs., the smaller cylinder will, at the end of the stroke, be full of steam of the same or nearly the same force; and the steam-vessel being full of the steam delivered to it by the former stroke of the small cylinder, at about 18lbs. pressure, the communication is opened between this vessel and the smaller cylinder, and the steam in each of these will be brought to nearly 20lbs. pressure, which steam will be used in the great cylinder at the next stroke. But at the end of each stroke of the pistons, before the opening is made between the smaller cylinder and the steam-vessel, the steam in the smaller cylinder will be, as before stated, at about 54lbs.; in the steam-vessel it will be at about 18lbs., and in the larger working cylinder at about 18lbs. also. Hence the medium pressure on the piston of the smaller cylinder will be about 35lbs. on the inch, while the medium pressure of the steam on the piston of the great cylinder will be about 19lbs. on the inch; for it will be about 20lbs. at the beginning, and about 18lbs. at the end of the stroke. If the steam-vessel be made larger, the difference at each end of the stroke will

not be ſo great. If the ſteam was let out at 54lbs. from the ſmaller cylinder to the open air, there would be but 39lbs. upon each inch of the piſton, in conſequence of the re-action of the atmoſphere, equivalent to about 15lbs. *per* inch: thus, by letting the ſteam paſs from the ſmaller cylinder to the ſteam-veſſel, inſtead of letting it out to the open air, it loſes about 4lbs. on the inch of the ſmall piſton, but it gains about 12lbs. on the inch of a piſton three times as large; and there being but half the ſteam required in the common way to condenſe, there muſt of neceſſity be a conſiderable gain. If the friction and loſs of force be equal to 9lbs. on the inch on the piſton of the ſmaller cylinder, there will be but about 30lbs. on the inch neat power, when the larger one will work about 12lbs. on the inch. Here too, if the large cylinder, or piſton, or air-pump, or condenſer, ſhould be out of order, the ſmall piſton may ſtill be worked, by diſengaging the large piſton from the beam: on the other hand, if the ſmaller piſton be out of order, the large one may ſtill be worked, while the other is diſengaged. The ſteam-veſſel is to be made of wood, that it may tranſmit the heat ſlowly, and the cylinders may be placed within it, if found convenient.

We have examined two engines of Mr. Deverell's which worked with great regularity, but the nature of the work they were performing did not admit of any accurate eſtimate of their power. The quantity of fuel they conſumed was but ſmall. We are diſpoſed to think the addition of the ſteam-veſſel for the ſteam to expand itſelf in, is advantageous in regulating the preſſure, provided the heat is kept up; and for this purpoſe, the ſteam-veſſel in one of the engines we ſpeak of was incloſed in the boiler, and we think would, in that caſe, receive a conſtant addition of heat to the expanded ſteam within it, which we believe is eſſential to all theſe kinds of engines. See the ſpecification at large in the Repertory of Arts, vol. viii. p. 81.

Meſſrs. Fox and Lean have alſo a patent, dated Dec. 10, 1802, for improvements on ſteam-engines, the principal part of which is a double-cylinder engine, very much reſembling thoſe which we have deſcribed. See the Repertory, vol. xxiii. p. 200.

Application of Reciprocating Engines to produce a rotative Motion for turning Machinery.—We have hitherto conſidered the ſteam-engine as being confined to the operation of working pumps for raiſing water; except in the ſlight notice which we have taken of the application of the crank to the atmoſpheric engine. This was a thing ſo obviouſly in imitation of the foot-lathe, as to be ſcarcely conſidered an invention; but the difficulty of applying it to uſe aroſe from the want of regularity in the action of the old engine. An engine to work a crank, muſt at all times make exactly the ſame length of ſtroke; and to perform well, all theſe ſtrokes muſt be performed in an equal period of time. The old engines had very little exactneſs in either of theſe particulars. From the nature of the detent which opened the injection-cock, and the great friction of turning it, the degree to which it was opened was not conſtantly the ſame in the ſucceeding ſtrokes; and a very ſmall difference of opening would materially influence the quantity of injection, and conſequently the vacuum and velocity with which the piſton would deſcend. The boilers alſo of the old engines were always made too ſmall, ſo that the leaſt alteration in the intenſity of the fire made the engine vary its ſpeed.

At preſent, in the coal-countries the atmoſpheric engines are made to work machinery by means of a crank, and perform very well, but they are lightly loaded, and move very quickly. The ſteam in the boiler is made much ſtronger than formerly, to enable it to fill the cylinder with a ſudden puff, and thus to diſplace the air and water in an inſtant, becauſe the rapid motion of the piſton will not allow ſufficient time for the diſcharging to be performed with weak ſteam, as is uſual. All theſe circumſtances reduce the performance of the engine with reſpect to coals, and the conſumption is very great in compariſon with the work they perform. Such engines act very well when the work or reſiſtance is conſtantly the ſame throughout the day; but the engine cannot work regularly, except when the counter-weight of the connecting rod is equal to half the deſcending force of the piſton, ſo as to make the ſtroke upon the crank of equal force in aſcending and deſcending. In breweries, and thoſe works which demand attention to varying reſiſtance, this cannot apply: for inſtance, when the machinery for grinding is diſengaged, or thrown off, if ſomething does not operate to retard the effect of the counter-weight, the engine will increaſe in its velocity beyond all bounds, ſo as to work itſelf to pieces; and as the only remedy is to check the quantity of ſteam at the returning ſtroke, the diſcharge of the air will be interrupted, and the engine muſt ſtop. Mr. Watt's ſingle engine accommodates this circumſtance, from the mode of diſcharging being conſtant, and not poſſible to be effected by the work applied to it, whether it be uniform or variable: hence, to leſſen the momentum of the counter-weight, it is only to check the entrance of the ſteam by any contrivance that will prevent the valve, which admits ſteam to enter above the piſton, from opening to its greateſt limits.

Mr. Watt, for ſome years after the firſt introduction of his engines, was ſo fully occupied in ſubſtituting them for the large atmoſpheric engines at mines, where the expence of fuel was threatening to put a ſtop to their proceedings, that he found no leiſure for new ſpeculations; and although the advantages of applying engines on his principle to actuate machinery had early occurred to him, he did not ſeriouſly ſet about reducing his ideas to practice until the year 1778 or 1779. In the firſt model he then made, in order to equalize the power, he employed two cylinders, acting upon two cranks fixed upon the ſame axis, at an angle of 120° from each other, and a weight was placed upon the circumference of the fly-wheel at an angle of 120° from each of the cranks; which weight was to be ſo adjuſted, as to turn the wheel when neither of the cranks could do ſo, and conſequently to render the power nearly equal. This model performed to ſatisfaction; but Mr. Watt having neglected to take out a patent immediately, the eſſential part of the contrivance was communicated, as we are informed in the Edinburgh Review, by a workman employed to make a model, to the perſons engaged about one of Mr. Waſhbrough's engines, of which we have before ſpoken, and a patent was taken out for the application of the crank by the engineer there employed. This did not deter Mr. Watt from proceeding; and without attempting to diſpute a patent which, ſo long as it continued attached to the common atmoſpheric engine, could not rival him, he ſet about other modes of effecting the ſame thing, and took out a patent for ſeveral new methods of applying the vibrating or reciprocating motion of ſteam-engines to produce a continued rotative motion round an axis, one of which was that beautiful contrivance of the revolving motion of one wheel round the other, called the ſun and planet wheels, from the reſemblance to the motion of thoſe luminaries. Mr. Watt's patent is dated October 1782, and entitled, a new method of applying the vibrating or reciprocating motion of ſteam-engines to produce a continued rotative or circular motion. It contains ſix different methods; but the two which have been ſince brought into uſe

are the crank, and sun and planet wheels. The crank is applied in the best manner to produce a regular motion, when a single acting engine is the moving power: this was to apply an iron wheel on the end of the axis of the fly-wheel for a crank, and with a pin projecting from it, to which the connecting rod is jointed: one half of the wheel is made solid, of cast-iron, in order to be heavy on that side in which the pin is fixed, so as to urge round the fly during the returning stroke of the engine; the other half of the wheel is made light, that it may not oppose this weight.

Soon after this patent, Mr. Watt erected some engines in London at the large breweries; the first was at Mr. Goodwyn's, a spirited encourager of improvements, and the next at Mr. Whitbread's. A sketch of the latter engine, which is still working, is given in our plate *Porter-Brewery*. In these engines he employed the sun and planet wheels, and used a massive connecting rod, of sufficient weight to actuate the fly during the returning stroke, for these engines had not the advantage of the double action.

Double-acting Steam-Engines.—The advantage of a double-acting engine, which shall urge the machinery equally in ascending and descending, is obvious. The first double-acting steam-engine was proposed in 1779, by Dr. Falck, who published an account and description of an improved steam-engine, which will, he says, with the same quantity of fuel, and in an equal space of time, raise above double the quantity of water raised by any lever-engine of the same dimensions; but he does not appear to have proved the assertion, or constructed even a working model of his proposed engine, which was on Newcomen's principle. The chief improvement which he suggests is to use two cylinders, into which the steam is alternately admitted by a common regulator, which always opens the communication of the steam to one, whilst it shuts up the opening of the other. The piston-rods are kept (by means of a wheel fixed to an arbor) in a continual ascending and descending motion, in the same manner as the rods of the common air-pump, by which they move a common axle; to which is affixed another wheel, moving the pump-rods in the same alternate direction as the piston-rods, by which alternate motions of the two pistons the pumps are kept in constant action. Since the improved engines of Mr. Watt have been introduced, this method of combining the alternate action of two single engines has been applied to work machinery. We have seen both the atmospheric engine and the single engine of Mr. Watt working in this manner, but his double engine is much preferable. Mr. Watt saw that this was necessary, in order to perfect the application of his steam-engine; he therefore applied the power of the steam to press the piston upwards in its cylinder as well as downwards, by forming the vacuum alternately above and below the piston, and the counter-weight then becomes unnecessary. The only change in the machine beside the arrangement of the valves and their mechanism, was in applying a double chain to the arch-head of the beam, in the same way that the pumps of old extinguishing engines were worked; or he employed a rack and sector at the end of the beam.

This he called the *double engine*, as in fact it doubled the power exerted within the same cylinder. He had long had in his mind the idea of this improvement, and had even produced a drawing of it to the house of commons, in 1774, at the time he procured the act to prolong his original patent for 25 years; but the first he executed was, we believe, at Soho, in the year 1781 or 1782, and the first public exhibition of it at the Albion mills a few years later.

About the same period, finding double chains, or racks and sectors, very inconvenient for communicating the motion of the beam, he invented and applied what has been called the *parallel motion*, one of the most ingenious and most perfect contrivances in mechanics. To prevent irregularities in the speed of the engine, arising from variations in the quantum of power used at different intervals in the works to which it was applied, he made an application of the centrifugal force of what is called the governor (before used in wind-mills), to regulate the admission of the steam; by this means keeping the engine always at an uniform velocity, and diminishing the consumption of steam, in proportion to the power exerted. This gave the finishing stroke to the perfection of the motion of the machine, and rendered its regularity nearly correspondent with that of the pendulum of a clock. These inventions are detailed, among many other contrivances, relative both to steam-engines and the application of their power, in two patents, dated 1782 and 1784. Some of these are highly ingenious; a few may have been first ideas, not reduced to practice, and others were no doubt inserted for the purpose of guarding against evasion.

Messrs. Boulton and Watt's Double-Acting Engine for turning Mills.—*Plate* VI. contains a general elevation of the whole engine, and *Plate* VII. *fig.* 1. is a section of the cylinder, inclosed in its steam-case or jacket, the outside of which is coated with plaster, to keep in the heat: the internal structure will be described hereafter: *a* is the piston-rod, connected to the great working beam C B E, by a system of levers *b*, *c*, *d*, *m*, called a parallel motion, the property of which is, that the rectilinear motion of the piston-rod, *a*, is preserved, though the end, C, of the beam describes an arc of a circle when it rises and falls upon its centre of motion, B. At the opposite end, E, of the beam is jointed the connecting rod D, and at the lower end of this is Mr. Watt's contrivance for communicating the force of the steam-engine to any machine of the rotatory kind. G represents the rim and arms of a very large and heavy cast-iron fly-wheel; on the extremity of its axis is fixed the concentric toothed wheel H, called the sun-wheel. The connecting rod, D I, is a strong and stiff iron rod, D, of sufficient weight to balance the piston: to the lower end of it, a toothed wheel, I, is firmly fixed by three bolts, so that it cannot turn round. This wheel is called the planet-wheel, because it revolves round the sun-wheel; it is of the same size and in the same vertical plane with the wheel H, and an iron link or strap (which cannot be seen here, because it is on the other side of the two wheels) connects the centres of the two wheels, so that the one cannot quit the other. The engine being in the position represented in the figure, to explain the action of this movement, suppose the fly, G, to be turned once round by any external force, in the direction from G towards K, it is plain, that since the toothed wheels, being kept together by the link, cannot quit each other, the outer half of the sun-wheel (that is, the half farthest from the cylinder) will work on the inner half of the planet-wheel I, so that at the end of the revolution of the fly, the planet-wheel must have arrived to the top of the sun-wheel H, because the circumferences of the wheels are equal, and the outer end, E, of the beam must be raised to its highest position. The next revolution of the fly will bring the planet-wheel, and the beam connected with it, to their first positions, and thus every two revolutions of the fly will make a complete period of the beam's reciprocating movements. Now, instead of supposing the fly to drive the beam, let the beam drive the fly, the motions must be precisely the same, and each ascent or descent of the piston will produce one revolution of the fly.

For inftance, when the pifton-rod, *a*, is caufed to afcend by the preffure of the fteam beneath its pifton, it raifes one end of the beam and depreffes the other; and by the communication of the connecting rod D, caufes the planet-wheel I, to turn the wheel H, and the fly-wheel, round with a double velocity. As foon as the pifton-rod arrives at the end of its ftroke, it receives a new impulfe, which brings it down again, and confequently raifes the connecting rod D, and planet-wheel I, fo as to continue the motion of the wheel H, and fly-wheel G, always in the fame direction. The ufe of the fly-wheel is to acquire an impetus from the force communicated to it, at the time that the centre of the planet-wheel, I, is on the fame horizontal line with the centre of the fun-wheel H, at which time the connecting rod exerts all the force of the engine upon the wheel H, to turn it round. This momentum is preferved by the rapid motion of the fly-wheel, which continues to turn all the reft of the machinery, when the planet-wheel, I, is at the top or bottom of its motion, for the centres of the two wheels being in a line with the connecting rod, it has no tendency to turn them round.

To defcribe the manner in which the power of the fteam is given to the pifton-rod *a*, we muft turn to the fection in *Plate* VII. *fig.* 1. where A is the jacket or fteam-cafe containing the cylinder, which is of caft-iron, and truly bored; it is clofed at top by an iron lid *l*, fcrewed on by fcrew-bolts, paffing through a projecting rim or flanch at the top, and a fimilar flanch is formed at the lower end of the cylinder, to faften on the bottom. In the centre of the top lid is a ftuffing-box, *l*, for holding a packing of hemp, through which the pifton-rod, *a a*, paffes, perfectly air and fteam tight: 20 is the pifton, packed with hemp in a channel round its edge, fo that the packing lies between its circumference and the infide furface of the cylinder; and while it can move up and down in the cylinder eafily, it will not allow any fteam to pafs by it. The pifton is fitted to the rod, *a*, with a cone, and faft keyed in: the cylinder has a flanch or projecting ring round it, a little below the top flanch, by which it is held into the jacket A, which is conftantly fupplied with fteam from the boiler of the engine, by a fmall pipe branching off from the fteam-pipe.

The fteam-pipe cannot be feen in the elevation, except by the fmall dark circle near *g*; and in *fig.* 2. it is marked 21: it introduces the fteam from the boiler, at all times, through a throttle-valve, 25, into a box *g*, called the upper fteam-box. In the bottom of this box is the upper fteam-valve, which being opened by depreffing the end of the lever 7, admits the fteam into the fhort paffage 14, which leads to the top of the cylinder. A branch, 12, defcends perpendicularly from the fteam-pipe, juft before it enters the upper fteam-box, and conveys fteam to the lower fteam-box *i*; and in the bottom of this is a valve, which can be opened by lifting the end of a lever, 10, to admit the fteam into the paffage 15, which leads into the bottom of the cylinder. Thefe two valves govern the entrance of fteam into the cylinder; and they both open upwards.

The valves for carrying off the fteam are fituated in two other boxes, *h* and *k*, in which a vacuum is always maintained by their open communication with the condenfer M, by the exhaufting-pipe 13, which defcends from the upper box *h*, and where it paffes by the lower box *k*, has a fmall branch leading into it.

Thefe two exhaufting boxes are fituated immediately beneath the paffages, 14 and 15, which lead to the top and bottom of the cylinder, and the exhaufting-valves are fituated in the horizontal plate of the partition between the boxes and the paffages, in the fame manner as the fteam-valves are in the partitions between the fteam-boxes and the fame paffages, as is clearly fhewn in *fig.* 3. On opening the upper exhaufting-valve, by depreffing the lever 8, the fteam from the top of the cylinder will be drawn off to the condenfer; or by elevating the lever 9 (*fig.* 2.), the lower exhaufting-valve will be opened, and the fteam will pafs off from the lower part of the cylinder to the condenfer.

The fteam and eduction-valves, 7, 8, 9, 10, are opened and fhut by the levers called fpanners, whofe handles, 1 and 2, are alternately moved by the plugs fixed to the pifton-rod of the air-pump N. This part of the machinery has been called the hand-gear, becaufe it is fo conftructed that the fteam and eduction-valves can be worked either by the hand or by the pifton of the air-pump.

The valves are connected in pairs to levers upon the axle of the two handles 1 and 2, which are actuated by the pins *f* and 24, projecting from the rod, *f*, of the air-pump, and the arrangement is this; the lower fteam-valve 10, and the upper exhaufting-valve 8, are connected by rods with levers upon the axle of the lower handle 2, and when that handle is depreffed it will open both thofe valves at once, to admit fteam below the pifton, and exhauft it from above, which will caufe the afcent of the pifton. A lever and rod 6, (fee the elevation) are applied to the axis of this handle, with a fufficient weight in the ciftern to caufe the handle to fall and open the valves fuddenly; but when the valves are to be kept fhut, the handle, 2, is held up by a catch, and detent 3 4, the end, 4, having a hook to receive the catch, and detain the handle when lifted up, as in the figure.

In the fame manner, the upper fteam-valve 7, and the lower exhaufting-valve 9, are united by rods to levers fixed upon the axis of the upper handle 1; and when this handle is raifed, as in the figure, it opens both valves at once, fo as to admit the fteam above the pifton and exhauft it from beneath it, as is fhewn by the arrows in the fection, which will caufe the pifton to defcend.

Like the former fpindle, a lever, 5, and rod are applied to it, with a weight which will lift up the handle, 1, and open the two valves; but when the handle is depreffed, fo as to fhut the valves, it is held down by the catch entering the hook, 3, of the detent 3 4. As this detent moves upon a centre-pin, it muft be obferved, that when one lever catches into the hook it pufhes back the detent, and this motion releafes the other catch from the hook at the oppofite end of the detent, fo that moving one handle to fhut one pair of valves releafes the catch, and the weights immediately open the oppofite pair of valves.

The exhaufting-pipe, 13, defcends to the condenfer M, which is a cylindrical veffel of caft-iron, immerfed in the cold water of the condenfing ciftern L; it communicates by the valve *m*, with the air pump N, which has valves in its bucket opening upwards, and is covered by a lid, through which the rod paffes in a ftuffing-box; alfo at the top of the pump is a fhort pipe of difcharge, opening into the hot-well *n*, and this has a valve to prevent the return of the air and water into the pump.

All thefe parts are exactly the fame as thofe of the fingle engine, before defcribed, except the injection-cock 16, which is conftantly running a fmall jet of cold water into the condenfer, when the engine is at work. There is no neceffity for an injection-valve in the double engine, and the ufe of the cock is only to regulate the quantity, and to ftop it when the engine is not at work: it is moved by a handle 17, and there is a divided plate and index, to fhew the degree of opening.

The cylinder is bolted down to two ſtrong beams, which croſs over the top of the condenſing ciſtern L, and theſe are united at the ends to two vertical poſts S, which are framed into another piece ſituated beneath the ciſtern, and ſupported upon a pier of brick-work R: by this means the whole weight of the water in the ciſtern is applied to hold the cylinder firmly down. K are beams which ſupport the ſtrain of the beam-centre, by bearing up the floor F, on which the centre bearing reſts; and the narrow dark line up the middle of the frame K, is a large iron bolt, which ties the frame down to the long groundſills, on which the ciſtern reſts, and with which the beam T, for the centre of the fly-wheel, is connected by oblique legs and tie-bolts: by this means the external walls, W, W, are relieved from any material ſtrain occaſioned by the working of the engine. X X is the ſtaircaſe to aſcend to the beam-floor. The boiler is not repreſented, but may be conſidered the ſame as that of the ſingle engine.

Operation of the Double Engine.—Suppoſing every thing in the poſition of the ſection, the operation of the engine is as follows. When the water in the boiler is heated by the fire made under its bottom, the heat which enters into combination with the water cauſes it to expand, and form ſteam: in this ſtate it riſes and fills the boiler, and thence paſſing through the pipes 21, enters the upper ſteam-box *g*; it alſo enters between the jacket, and warms the cylinder; and by the deſcending branch, 12, of the ſteam-pipe, enters and fills the lower ſteam-box *i*. Before the engine can be worked, the ſteam muſt be heated, until it is expanded ſo much, that it will ruſh forcibly out of the boiler when permitted.

The perſon who attends the engine muſt now open all the four valves at once, by elevating the handle 1, and depreſſing the handle 2; this admits the ſteam from the boiler to paſs through the boxes and the cylinder to the condenſer, when it ruſhes through the pipe, 13, into the condenſer M, driving the air therein contained through the valve *m*, and the valves in the bucket of the air-pump, which it opens, and paſſes into the ciſtern *n*, through the diſcharge-valve, where it is open to the atmoſphere, the lid of that ciſtern being only laid on, and not fitting tight. This operation (called blowing through) being continued for a few ſeconds, expels all the air from the condenſer, and fills it with hot ſteam. All the four valves are now cloſed, by preſſing down the upper handle 1, and lifting up the lower handle 2; and the injection-cock 16, of which 17 is the handle, is opened: this allows a ſmall ſtream of cold water from the condenſing ciſtern, L, to enter into the condenſer, and condenſes the ſteam or cools it, when it inſtantly contracts into the ſame ſpace it originally occupied in the boiler, before it was heated. As the valve, *m*, cloſes, to prevent the return of the atmoſpheric air, a vacuum will be cauſed in the condenſer, becauſe there will be nothing in it but that ſmall quantity of water produced from the ſteam, and the cold water injected into the condenſer.

The engine-man now opens the upper condenſing valve 8, and lower ſteam-valve 10, by allowing the lower handle, 2, to fall down. The communication to the condenſer being thus opened, the mixture of air and ſteam in the upper part of the cylinder will expand itſelf into the condenſer through the paſſage 14, and valve 8, by the exhauſting-pipe 13: as it occupies more ſpace than it did before, it will be conſiderably rarefied, and preſs lightly upon the upper ſide of the piſton. The ſteam from the boiler entering through the open valve, 10, is all the while preſſing with its full force againſt the lower ſide of the piſton, and will perhaps, now a rarefaction is made above it, overcome the reſiſtance of the work and friction, and cauſe the piſton to aſcend, the air-pump rod and bucket moving with it. When the pin 24, upon this rod, reaches the handle 2, it raiſes it up, and ſhuts the lower ſteam-valve 10, and the upper exhauſting-valve 8; and by means of the catch preſſing back the hook at the lower end of the detent 4, it relieves the catch of the upper handle from the hook, 3, of the detent; in conſequence of which, the weight applied to the lever 5, throws up the handle 1, and opens the upper ſteam-valve 7, and lower exhauſting-valve 9, while the hook, 4, of the detent, receiving the catch of the lower handle 2, holds it up. This is the ſituation repreſented in the ſection in *fig.* 1. The operation is now reverſed; the ſteam from the boiler going through the valve 7, and paſſage 14, into the cylinder above the piſton, as ſhewn by the arrows, *fig.* 1; and that ſteam which is beneath the piſton going through the paſſage 15, and valve 9, to the condenſer, where the ſteam will be condenſed, and a vacuum will be formed beneath the piſton: the ſteam now preſſes it down, moving the beam, and turning the fly-wheel and other machinery which it has to drive. When the piſton is at the bottom, the pin, *f*, on the air-pump rod arrives at the handle 1, and preſſes it down; this ſhuts the upper ſteam-valve 7, and lower exhauſting-valve 9; and when they are completely ſhut, the catch of the upper handle, in entering the upper hook of the detent 3 4, diſengages the lower hook thereof; and the weight 6, which is applied to the lower handle 2, immediately throws open the lower ſteam-valve 10, and the upper exhauſting-valve 8: the ſteam entering at the lower paſſage 15, the piſton will be driven up again.

At each ſtroke of the engine, when the piſton riſes, the valve in the bucket of the air-pump will ſhut, and all the air and water contained above the bucket will be lifted through the valve, *n*, into the ciſtern or hot-well; at the ſame time, a vacuum being made beneath the bucket, which is more perfect than that in the condenſer, the valve, *m*, will be opened by the water and air in the condenſer, which will enter the pump. On the deſcent of the piſton, and air-pump bucket, the valve *m*, and the diſcharging-valve, *n*, will be ſhut, becauſe the preſſure which opened them is removed; and the water and air in the pump preſſing upon the valves in the bucket will open them, and paſs through the bucket as it deſcends. At its return, it raiſes and diſcharges the water and air above it at the valve *n*, as before.

In this manner, when the engine has made two ſtrokes, all the air which was contained in the cylinder, and mixed with the ſteam at the commencement of the operation, which was the only part from which it could not be expelled by blowing through, will be pumped out. The operation of the engine is now more perfect; the inſtant the exhauſting-valve is opened, ſo as to eſtabliſh a communication from the cylinder full of ſteam to the condenſer, the elaſticity of the ſteam cauſes it to ruſh through the valve, down the pipe 13, into the condenſer: when it arrives there, it meets the ſtream of the injection-water, which condenſes it, the remaining ſteam in the cylinder following it ſurpriſingly quick; and in an inſtant, an almoſt perfect vacuum is formed in the cylinder, ſo that the ſteam acts with its whole force upon the piſton to give it motion, all reſiſtance upon the other ſide being removed.

The air-pump has now only to draw off from the condenſer the water injected into it, the water produced by the condenſed ſteam, and that ſmall quantity of air or gas which goes from the boiler with the ſteam, and will not be condenſed by the cold water. Theſe are delivered

For inſtance, when the piſton-rod, *a*, is cauſed to aſcend by the preſſure of the ſteam beneath its piſton, it raiſes one end of the beam and depreſſes the other; and by the communication of the connecting rod D, cauſes the planet-wheel I, to turn the wheel H, and the fly-wheel, round with a double velocity. As ſoon as the piſton-rod arrives at the end of its ſtroke, it receives a new impulſe, which brings it down again, and conſequently raiſes the connecting rod D, and planet-wheel I, ſo as to continue the motion of the wheel H, and fly-wheel G, always in the ſame direction. The uſe of the fly-wheel is to acquire an impetus from the force communicated to it, at the time that the centre of the planet-wheel, I, is on the ſame horizontal line with the centre of the ſun-wheel H, at which time the connecting rod exerts all the force of the engine upon the wheel H, to turn it round. This momentum is preſerved by the rapid motion of the fly-wheel, which continues to turn all the reſt of the machinery, when the planet-wheel, I, is at the top or bottom of its motion, for the centres of the two wheels being in a line with the connecting rod, it has no tendency to turn them round.

To deſcribe the manner in which the power of the ſteam is given to the piſton-rod *a*, we muſt turn to the ſection in *Plate* VII. *fig.* 1. where A is the jacket or ſteam-caſe containing the cylinder, which is of caſt-iron, and truly bored; it is cloſed at top by an iron lid *l*, ſcrewed on by ſcrew-bolts, paſſing through a projecting rim or flanch at the top, and a ſimilar flanch is formed at the lower end of the cylinder, to faſten on the bottom. In the centre of the top lid is a ſtuffing-box, *l*, for holding a packing of hemp, through which the piſton-rod, *a a*, paſſes, perfectly air and ſteam tight: 20 is the piſton, packed with hemp in a channel round its edge, ſo that the packing lies between its circumference and the inſide ſurface of the cylinder; and while it can move up and down in the cylinder eaſily, it will not allow any ſteam to paſs by it. The piſton is fitted to the rod, *a*, with a cone, and faſt keyed in: the cylinder has a flanch or projecting ring round it, a little below the top flanch, by which it is held into the jacket A, which is conſtantly ſupplied with ſteam from the boiler of the engine, by a ſmall pipe branching off from the ſteam-pipe.

The ſteam-pipe cannot be ſeen in the elevation, except by the ſmall dark circle near *g*; and in *fig.* 2. it is marked 21: it introduces the ſteam from the boiler, at all times, through a throttle-valve, 25, into a box *g*, called the upper ſteam-box. In the bottom of this box is the upper ſteam-valve, which being opened by depreſſing the end of the lever 7, admits the ſteam into the ſhort paſſage 14, which leads to the top of the cylinder. A branch, 12, deſcends perpendicularly from the ſteam-pipe, juſt before it enters the upper ſteam-box, and conveys ſteam to the lower ſteam-box *i*; and in the bottom of this is a valve, which can be opened by lifting the end of a lever, 10, to admit the ſteam into the paſſage 15, which leads into the bottom of the cylinder. Theſe two valves govern the entrance of ſteam into the cylinder; and they both open upwards.

The valves for carrying off the ſteam are ſituated in two other boxes, *h* and *k*, in which a vacuum is always maintained by their open communication with the condenſer M, by the exhauſting-pipe 13, which deſcends from the upper box *h*, and where it paſſes by the lower box *k*, has a ſmall branch leading into it.

Theſe two exhauſting boxes are ſituated immediately beneath the paſſages, 14 and 15, which lead to the top and bottom of the cylinder, and the exhauſting-valves are ſituated in the horizontal plate of the partition between the boxes and the paſſages, in the ſame manner as the ſteam-valves are in the partitions between the ſteam-boxes and the ſame paſſages, as is clearly ſhewn in *fig.* 3. On opening the upper exhauſting-valve, by depreſſing the lever 8, the ſteam from the top of the cylinder will be drawn off to the condenſer; or by elevating the lever 9 (*fig.* 2.), the lower exhauſting-valve will be opened, and the ſteam will paſs off from the lower part of the cylinder to the condenſer.

The ſteam and eduction-valves, 7, 8, 9, 10, are opened and ſhut by the levers called ſpanners, whoſe handles, 1 and 2, are alternately moved by the plugs fixed to the piſton-rod of the air-pump N. This part of the machinery has been called the hand-gear, becauſe it is ſo conſtructed that the ſteam and eduction-valves can be worked either by the hand or by the piſton of the air-pump.

The valves are connected in pairs to levers upon the axle of the two handles 1 and 2, which are actuated by the pins *f* and 24, projecting from the rod, *f*, of the air-pump, and the arrangement is this; the lower ſteam-valve 10, and the upper exhauſting-valve 8, are connected by rods with levers upon the axle of the lower handle 2, and when that handle is depreſſed it will open both thoſe valves at once, to admit ſteam below the piſton, and exhauſt it from above, which will cauſe the aſcent of the piſton. A lever and rod 6, (ſee the elevation) are applied to the axis of this handle, with a ſufficient weight in the ciſtern to cauſe the handle to fall and open the valves ſuddenly; but when the valves are to be kept ſhut, the handle, 2, is held up by a catch, and detent 3 4, the end, 4, having a hook to receive the catch, and detain the handle when lifted up, as in the figure.

In the ſame manner, the upper ſteam-valve 7, and the lower exhauſting-valve 9, are united by rods to levers fixed upon the axis of the upper handle 1; and when this handle is raiſed, as in the figure, it opens both valves at once, ſo as to admit the ſteam above the piſton and exhauſt it from beneath it, as is ſhewn by the arrows in the ſection, which will cauſe the piſton to deſcend.

Like the former ſpindle, a lever, 5, and rod are applied to it, with a weight which will lift up the handle, 1, and open the two valves; but when the handle is depreſſed, ſo as to ſhut the valves, it is held down by the catch entering the hook, 3, of the detent 3 4. As this detent moves upon a centre-pin, it muſt be obſerved, that when one lever catches into the hook it puſhes back the detent, and this motion releaſes the other catch from the hook at the oppoſite end of the detent, ſo that moving one handle to ſhut one pair of valves releaſes the catch, and the weights immediately open the oppoſite pair of valves.

The exhauſting-pipe, 13, deſcends to the condenſer M, which is a cylindrical veſſel of caſt-iron, immerſed in the cold water of the condenſing ciſtern L; it communicates by the valve *m*, with the air pump N, which has valves in its bucket opening upwards, and is covered by a lid, through which the rod paſſes in a ſtuffing-box; alſo at the top of the pump is a ſhort pipe of diſcharge, opening into the hot-well *n*, and this has a valve to prevent the return of the air and water into the pump.

All theſe parts are exactly the ſame as thoſe of the ſingle engine, before deſcribed, except the injection-cock 16, which is conſtantly running a ſmall jet of cold water into the condenſer, when the engine is at work. There is no neceſſity for an injection-valve in the double engine, and the uſe of the cock is only to regulate the quantity, and to ſtop it when the engine is not at work: it is moved by a handle 17, and there is a divided plate and index, to ſhew the degree of opening.

The cylinder is bolted down to two ſtrong beams, which croſs over the top of the condenſing ciſtern L, and theſe are united at the ends to two vertical poſts S, which are framed into another piece ſituated beneath the ciſtern, and ſupported upon a pier of brick-work R: by this means the whole weight of the water in the ciſtern is applied to hold the cylinder firmly down. K are beams which ſupport the ſtrain of the beam-centre, by bearing up the floor F, on which the centre bearing reſts; and the narrow dark line up the middle of the frame K, is a large iron bolt, which ties the frame down to the long groundſills, on which the ciſtern reſts, and with which the beam T, for the centre of the fly-wheel, is connected by oblique legs and tie-bolts: by this means the external walls, W, W, are relieved from any material ſtrain occaſioned by the working of the engine. X X is the ſtaircaſe to aſcend to the beam-floor. The boiler is not repreſented, but may be conſidered the ſame as that of the ſingle engine.

Operation of the Double Engine.—Suppoſing every thing in the poſition of the ſection, the operation of the engine is as follows. When the water in the boiler is heated by the fire made under its bottom, the heat which enters into combination with the water cauſes it to expand, and form ſteam: in this ſtate it riſes and fills the boiler, and thence paſſing through the pipes 21, enters the upper ſteam-box *g*; it alſo enters between the jacket, and warms the cylinder; and by the deſcending branch, 12, of the ſteam-pipe, enters and fills the lower ſteam-box *i*. Before the engine can be worked, the ſteam muſt be heated, until it is expanded ſo much, that it will ruſh forcibly out of the boiler when permitted.

The perſon who attends the engine muſt now open all the four valves at once, by elevating the handle 1, and depreſſing the handle 2; this admits the ſteam from the boiler to paſs through the boxes and the cylinder to the condenſer, when it ruſhes through the pipe, 13, into the condenſer M, driving the air therein contained through the valve *m*, and the valves in the bucket of the air-pump, which it opens, and paſſes into the ciſtern *n*, through the diſcharge-valve, where it is open to the atmoſphere, the lid of that ciſtern being only laid on, and not fitting tight. This operation (called blowing through) being continued for a few ſeconds, expels all the air from the condenſer, and fills it with hot ſteam. All the four valves are now cloſed, by preſſing down the upper handle 1, and lifting up the lower handle 2; and the injection-cock 16, of which 17 is the handle, is opened: this allows a ſmall ſtream of cold water from the condenſing ciſtern, L, to enter into the condenſer, and condenſes the ſteam or cools it, when it inſtantly contracts into the ſame ſpace it originally occupied in the boiler, before it was heated. As the valve, *m*, cloſes, to prevent the return of the atmoſpheric air, a vacuum will be cauſed in the condenſer, becauſe there will be nothing in it but that ſmall quantity of water produced from the ſteam, and the cold water injected into the condenſer.

The engine-man now opens the upper condenſing valve 8, and lower ſteam-valve 10, by allowing the lower handle, 2, to fall down. The communication to the condenſer being thus opened, the mixture of air and ſteam in the upper part of the cylinder will expand itſelf into the condenſer through the paſſage 14, and valve 8, by the exhauſting-pipe 13: as it occupies more ſpace than it did before, it will be conſiderably rarefied, and preſs lightly upon the upper ſide of the piſton. The ſteam from the boiler entering through the open valve, 10, is all the while preſſing with its full force againſt the lower ſide of the piſton, and will perhaps, now a rarefaction is made above it, overcome the reſiſtance of the work and friction, and cauſe the piſton to aſcend, the air-pump rod and bucket moving with it. When the pin 24, upon this rod, reaches the handle 2, it raiſes it up, and ſhuts the lower ſteam-valve 10, and the upper exhauſting-valve 8; and by means of the catch preſſing back the hook at the lower end of the detent 4, it relieves the catch of the upper handle from the hook, 3, of the detent; in conſequence of which, the weight applied to the lever 5, throws up the handle 1, and opens the upper ſteam-valve 7, and lower exhauſting-valve 9, while the hook, 4, of the detent, receiving the catch of the lower handle 2, holds it up. This is the ſituation repreſented in the ſection in *fig.* 1. The operation is now reverſed; the ſteam from the boiler going through the valve 7, and paſſage 14, into the cylinder above the piſton, as ſhewn by the arrows, *fig.* 1; and that ſteam which is beneath the piſton going through the paſſage 15, and valve 9, to the condenſer, where the ſteam will be condenſed, and a vacuum will be formed beneath the piſton: the ſteam now preſſes it down, moving the beam, and turning the fly-wheel and other machinery which it has to drive. When the piſton is at the bottom, the pin, *f*, on the air-pump rod arrives at the handle 1, and preſſes it down; this ſhuts the upper ſteam-valve 7, and lower exhauſting-valve 9; and when they are completely ſhut, the catch of the upper handle, in entering the upper hook of the detent 3 4, diſengages the lower hook thereof; and the weight 6, which is applied to the lower handle 2, immediately throws open the lower ſteam-valve 10, and the upper exhauſting-valve 8: the ſteam entering at the lower paſſage 15, the piſton will be driven up again.

At each ſtroke of the engine, when the piſton riſes, the valve in the bucket of the air-pump will ſhut, and all the air and water contained above the bucket will be lifted through the valve, *n*, into the ciſtern or hot-well; at the ſame time, a vacuum being made beneath the bucket, which is more perfect than that in the condenſer, the valve, *m*, will be opened by the water and air in the condenſer, which will enter the pump. On the deſcent of the piſton, and air-pump bucket, the valve *m*, and the diſcharging-valve, *n*, will be ſhut, becauſe the preſſure which opened them is removed; and the water and air in the pump preſſing upon the valves in the bucket will open them, and paſs through the bucket as it deſcends. At its return, it raiſes and diſcharges the water and air above it at the valve *n*, as before.

In this manner, when the engine has made two ſtrokes, all the air which was contained in the cylinder, and mixed with the ſteam at the commencement of the operation, which was the only part from which it could not be expelled by blowing through, will be pumped out. The operation of the engine is now more perfect; the inſtant the exhauſting-valve is opened, ſo as to eſtabliſh a communication from the cylinder full of ſteam to the condenſer, the elaſticity of the ſteam cauſes it to ruſh through the valve, down the pipe 13, into the condenſer: when it arrives there, it meets the ſtream of the injection-water, which condenſes it, the remaining ſteam in the cylinder following it ſurpriſingly quick; and in an inſtant, an almoſt perfect vacuum is formed in the cylinder, ſo that the ſteam acts with its whole force upon the piſton to give it motion, all reſiſtance upon the other ſide being removed.

The air-pump has now only to draw off from the condenſer the water injected into it, the water produced by the condenſed ſteam, and that ſmall quantity of air or gas which goes from the boiler with the ſteam, and will not be condenſed by the cold water. Theſe are delivered

by the air-pump into the hot-well, *n*, from which the air escapes; and the water, which still continues hot, runs off, when at a certain level, by a waste-pipe, which is not represented.

The water which is boiled off in steam from the boiler, is renewed from the hot-well by means of a small pump, *p*, in the elevation, which draws the water from it by a pipe *o*, conducted up the side of the great frame K, which stands at the end of the condensing cistern L, and supports the bearing for the centre of the great beam. The water is conveyed from the pump by a pipe, to a cistern placed at the top of a vertical pipe, which descends into the boiler. The top of this pipe is closed by a valve in the cistern, which valve is raised by means of a lever, and the other end has a wire hooked to it, going through a small stuffing-box into the boiler, where a stone is hung to it. This stone is balanced by a weight suspended at the other end of the lever, so that when the stone is covered with water, the weight keeps the valve shut, and prevents any water getting down into the boiler; but as the water sinks in the boiler by the evaporation, the weight of the stone overcomes the weight, and opens the valve: the water in the cistern then runs down the pipe into the boiler, and raises the water therein, and the balance-weight lifts up the stone, so as to close the valve.

The condenser being constantly supplied with hot steam, which gives out its heat, it would at length render the water surrounding it in the cistern so hot, that it would condense no more. To prevent this, it is constantly supplied with cold water from a pump O, worked by a rod P, from the great beam. The water from the condensing cistern runs off by a waste-pipe at the back of the cistern, but not seen in the figures. The safety-valve is contained in a short pipe fixed upon the boiler, with a lid and a stuffing-box, through which a rod passes to open the valve within, and discharge the steam when the engine is not to be worked any longer. When at work, the valve is pressed down by a lever and weight. If at any time, when the engine is not at work, the steam should be heated, so as to be in any danger of bursting the boiler, the valve will lift up the weight, and allow the steam to escape through the pipe which opens into the chimney.

Other Particulars of the Double Engine. — Mr. Watt's mode of regulating the engine is a most beautiful contrivance, and so perfect, as to put the steam-engine on an equality with a water-wheel, in the regularity of its motion, even when the resistance is very variable. The throttle-valve, which regulates the supply of steam, is placed in the steam-pipe at 25 (*Plate* VII. *fig.* 2.): it is a thin circular vane in the pipe, turning on a pivot across its centre, which comes through the pipe, and has a small handle fixed on the end of it: by turning this handle, the spindle and vane within the pipe are turned also. When the vane is set, so that its plane is perpendicular to the axis of the pipe, it nearly fills the circular passage, and allows very little steam, if any, to pass by it; but when the vane is turned edgeways, it presents a very small surface, and the steam passes by without obstruction to the steam-boxes *g* and *i*. By turning the handle of the throttle-valve, the engine-man can at any time regulate the speed of the engine, the friction of the axis being sufficient to retain it as it is placed.

This method of regulation is sufficient for many engines; but when the steam-engine is employed to drive machinery, in which the resistance is very variable, and where a determinate velocity cannot properly be dispensed with, Mr. Watt has applied the conical pendulum, which is represented in the elevation (*Plate* VI.) at *b s*, for procuring uniform velocity. (See also REGULATOR and MILL-WORK) This regulator has two pendulums, consisting of heavy balls, *b*, *s*, suspended by iron rods, which move on a common joint, *v*, at the top of the vertical axis *t x*, which is put in motion by an endless rope, *q*, passing round a pulley on the axis of the fly-wheel, and round another pulley upon a small horizontal axis, from which, by means of a pair of bevelled wheels, *r*, the motion is communicated to the vertical axis *t x*, which is caused to revolve, and carry the pendulum with it. In this motion, their balls, *b* and *s*, describe a horizontal circle, and the velocity is sufficient to make the balls fly out by their centrifugal force, the arms of the pendulums moving upon their centres: in this motion, the upper ends of the arms *w*, *w*, draw down a collar, *x*, which slides on the square part of the axis, and operates on a lever *x*, and by another lever *y*, and rod *z*, communicates with the steam or throttle-valve. The action of this beautiful contrivance is this: as the velocity of the fly-wheel increases and diminishes with the quantity of steam that is admitted into the cylinder, let us suppose that too much is admitted; then the velocity of the fly-wheel is increased, and the velocity of the vertical axis, *t x*, will also increase, and the balls *b*, *s*, will recede from the axis by the augmentation of their centrifugal force. By this recess of the balls, the extremity, *x*, of the lever is depressed, its other extremity rises, and acting upon the lever *y*, causes the vane of the throttle-valve to present more surface, to close the passage a little, and diminish the supply of steam. The impelling power of the engine being thus diminished, the velocity of the fly-wheel and the flying balls decreases in proportion, and the balls resume their former position, and the engine works regularly.

The advantage of the sun and planet wheels has been stated to consist in making the fly-wheel revolve with a double velocity to that which would be produced by a simple crank, by which means a fly-wheel of smaller dimensions becomes sufficient to regulate the motion of the engine. Of late years, this ingenious contrivance has been laid aside in favour of the simple crank, because it has been found that the cogs of the two wheels, when they become worn and loose, act with a disagreeable jerk at every change of the motion from the ascent to the descent. As it is in many cases an advantage to make the fly-wheel revolve with a double or triple velocity, a large cog-wheel is applied upon the axis of the crank, and this turns a pinion of only one-half or one-third of the size, fixed upon the axis of the fly-wheel. Here the same defect of the jerk, by the looseness of the cogs, will be experienced; but the wheels being larger than can be used in the sun and planet wheels, a greater number of cogs are brought into action, and the wear upon each will be less: also, this form of the engine can be included in less room, because the centre of the large fly-wheel may be brought beneath the middle of the beam.

The power of the engine, when transmitted by the crank, is extremely variable throughout the different periods of the stroke: at first beginning, the crank being in a line with the connecting rod, the force of the piston has no action at all to turn the crank; but as the crank begins to make a sensible angle with the connecting rod, the force of the piston begins to operate upon the crank to turn it round, and this with a force increasing with the angle at which the connecting rod acts upon the crank, until they are at right angles to each other; and then the whole force of the piston operates to drive round the crank. To shew the increments and decrements of this varying force, we have made out the following table from a projection of an engine on a large scale.

A Table ſhewing the force which the connecting rod of a ſteam-engine has to turn round the crank at different parts of the motion. The parts of the engine are ſuppoſed to have the following proportions: length of the ſtroke, 1.; length of the beam, 2.; length of the crank, .5; length of the connecting rod, 3.

Decimal Portions of the Deſcent of the Piſton, the whole Deſcent being 1.	Angle between the Connecting Rod and Crank.	Effective Length of the Lever upon which the Connecting Rod acts, the whole Crank being 1.	Decimal Portion Half a Revolution of the Fly-Wheel.
	Degrees.		
.0	180	.0	.0
.05	151½	.46	.128
.10	141	.62	.158
.15	131½	.74	.228
.2	123½	.830	.271
.25	117¼	.892	.308
.3	110¾	.94	.342
.35	104	.976	.377
.4	97½	.986	.41
.45	91¼	1.	.441
.5	85½	1.	.473
.55	80	.986	.507
.6	75	.956	.538
.65	69	.92	.572
.7	62½	.88	.607
.75	57¼	.824	.642
.8	49	.746	.68
.85	42	.66	.723
.9	34	.546	.776
.95	23½	.390	.84
1.0	0	.0	1.

☞ The third column of this table alſo ſhews the force which is communicated to the fly-wheel, expreſſed in decimals, the force of the piſton being 1.

The above table explains itſelf by the titles of its different columns, and it is only neceſſary to remark, that the variations of force are not to be conſidered as an abſolute loſs of power, becauſe, when the crank has but ſlight power, on arriving towards the top or bottom of the ſtroke, the piſton deſcends proportionably ſlow; and, in conſequence, the ſteam has more time to flow into the cylinder, and preſs upon the piſton with a greater power; therefore, what the piſton loſes in force upon the crank, it makes up in ſome degree by an increaſe of its force; and, from moving ſlower, it conſumes leſs ſteam than when moving with its whole velocity, and acting with full force upon the crank. Hence both the power and velocity of the piſton in the cylinder are to be conſidered as varying continually; and if the fly is ſufficiently heavy, it will be found that the rotative motion is very nearly regular, while the aſcent and deſcent of the piſton are accelerated from nothing at the top of the cylinder, to its greateſt velocity at the middle, or near the middle, and from that point it is retarded till it comes to nothing at the bottom of the motion. The table ſhews the exact increments and decrements.

It has been conſidered deſirable to have ſuch a motion, that the power and velocity communicated to the fly-wheel ſhall be at all times equable and conſtant. This was one of the firſt attempts to produce a rotatory motion, as we have mentioned, by Mr. Fitzgerald, at Hartley colliery, in 1768: it has been repeatedly attempted ſince that period. The moſt practicable form in which it has been tried was by Mr. Matthew Murray, who, in a patent dated 1799, for the improvement of ſteam-engines, deſcribes a very ingenious movement for the purpoſe. The defect of all theſe contrivances for obtaining equal power on the rotative axis is, that the piſton muſt act upon it all at once with a ſudden ſhock, which in courſe of time deſtroys the beſt conſtructed mechaniſm.

In the Philoſophical Journal is a deſcription of a contrivance by Mr. Samuel Clegg, for producing a rotative motion from a reciprocating one, which not only ſimplifies the machine very much, but exceeds the power of the common crank one-third, in conſequence of its action being always perpendicular to the radius of the wheel, which is done by a vertical double rack and wheel. The two vertical parts of this rack are joined by a ſemicircle at the top, and both parts are teethed on the inſide, ſo that the teeth of the vertical wheel are conſtantly in contact with ſome of the teeth of the fork formed by the two vertical bars and the ſemicircle uniting the double racks. The wheel and rack are conſtantly kept in gear by means of a ſmall roller, a ſliding-bar, and a plate, ſerving, inſtead of a groove, to keep the roller from deviation in this way. Although the change from the upward to the downward motion of the piſton-rod will be gradual, the change from the downward to the upward motion muſt be inſtantaneous; or at leaſt the piſton-rod muſt be brought to reſt at once, from an uniform motion downwards, and then receive inſtantaneouſly a finite velocity in the oppoſite direction.

A mode of giving a more uniform action to the crank, was attempted in an engine erected by Mr. Hornblower about 1795, at the brewery of Meſſrs. Meux and Co., where the alternate power of two ſingle cylinders was applied by chains acting upon circular arcs, at a conſtant diſtance from the centre of the lever; while the end of the lever which was connected to the crank by the connecting rod continually varied in its action, and conſequently in its force on the crank, nearly in an equal proportion to the alteration of the leverage of the crank. (See the ſketch of this contrivance at *fig.* 7. *Plate* V.) The two cylinders A, B, of this engine made an alternate action on a band-wheel, D, by means of two chains. The lever which carried the connecting rod, F, was a wheel fixed on the ſame ſhaft with the band-wheel, and had a pin, E, near its periphery, to which the connecting rod, F, was attached. This pin traverſed about 120° of the whole circle, and may be denominated the end of the lever, which, in its action upward to *e*, and downward to *f*, acceded and receded to and from the centre of motion; and had it traverſed through the remainder of the ſemicircle, it would then have preſſed on the crank, G, proportionately to the ſine of every angle it made in its revolution. But conſidering the great preſſure on this pin in the crank-wheel, it would have demanded a degree of ſtrength in that part which would have been prepoſterous, compared with the reſt of the work.

This engine has its merits and its defects; it is ſubject to much more friction than a double-acting cylinder, by having two cylinders and their appendages; and unleſs the communication between the cylinders is clothed with the beſt materials for that purpoſe, a great loſs of heat muſt enſue; becauſe the ſurface expoſed in two cylinders, compared with one double-acting cylinder, is as 2 to 1, and the friction of the piſtons will be nearly in the ſame proportion.

The air-pumps in this engine (for it had two, though only one condenſer) were worked by a ſmall band-wheel, upon the ſame axis as the great band-wheel D; and from the oppoſite ſides of this, the rods, *i k*, were ſuſpended by chains. The air-pumps were open at top, and the preſſure of the atmoſphere always reſted upon their piſtons; but as the two were acting in oppoſite directions, they balanced each other as to

power: in this the inventor adopted the common double-barrelled air-pump of Haukfbec, inftead of the more perfect air-pump of Smeaton, which Mr. Watt employs. This engine was confidered of 36 horfes' power, and for many years performed all the work of the brewery. We have alfo feen fome fmaller engines built on the fame plan, one of them with atmofpheric cylinders.

It may be confidered as an advantage in this engine, that it has a double air-pump, whereas the double cylinder has only a fingle air-pump, which draws out the air from the condenfer while the pifton is making its afcending ftroke; but during the defcent of the pifton the air-pump is inactive. We have feen many propofals for double-acting pumps.

Mr. Murray, in 1801, had a patent for a new air-pump, (fee the fpecification in the Repertory of Arts, firft feries, vol. xvi.); but we have not had an opportunity of afcertaining the performance of an engine fo conftructed; and as the ingenious inventor does not now adopt it in the fteam-engines which he makes, we may prefume it is not of great importance.

The proportion ufually given to the air-pump of a double engine is about two-thirds the diameter of the cylinder, and half the ftroke, or from one-fourth to one-fifth the capacity of the cylinder: the condenfer is of the fame fize. Whether it is owing to the circumftance of the fingle air-pump or not, we are unable to determine; but it appears that double-acting engines do not in general produce fo great an effect from the fuel they confume as fingle engines of the fame dimenfions. In Meffrs. Leans' reports of the engines in Cornwall, which generally contain the accounts of 20 or 25 engines, there are feveral enormous double engines for pumping the mines, with cylinders of 66 and 65 inches, and four of 63 inches. The beft of thefe appear to be on Williams' mine; cylinder 65 inches diameter, and working with a ftroke of 8 feet 9 inches, under a preffure of 16.6 lbs. *per* fquare inch: it works 10 pumps, which are a load of 70,411 lbs., at the rate of $6\frac{1}{2}$ ftrokes *per* minute, of 6 feet 9 inches each. Its performance with refpect to coals was, in June 1816, 30,074,507 lbs. lifted one foot high for each bufhel confumed. This is a very good performance; but all the other double engines are lefs, one of the 63-inch cylinders is 27 millions, the others 25, 22, 21, and even 17 millions.

The advantages are all on the fide of the double engine; the diminution of furface which is expofed to condenfation, the vis inertiæ of the parts in motion is much lefs, and the friction of the pifton is very much reduced, although the friction of the joints for communicating the motion muft be increafed, becaufe they muft be bound tight, fo as to have no fhake or loofenefs; but this muft be inconfiderable.

Before quitting the fubject of double engines, employed to give a rotative motion to machinery by a crank, we muft notice the remarkable difference, fhewn by Meffrs. Leans' reports, between the performance of the fmall engines employed in drawing the matter out of the mines, and thofe in pumping water.

We fhould think the lofs of power from friction in drawing up buckets by a rope, could not be greater than the friction of pump-buckets, and of the water moving in the pipes; therefore all the difference muft be attributed to the application to the rotative motion, and to the fmallnefs of the engines: thefe are ufually 14, 16, and 24 inches in diameter, but their performance, with refpect to coals, is only 3, $3\frac{3}{4}$, 4, and 5 millions. The beft engine they have draws only from $9\frac{1}{2}$ to 11 million pounds one foot high for each bufhel of coals, which is only one-third of the produce of the beft large engines employed in pumping.

One of Woolf's double engines at Wheal Fortune mine, in May, 1816, drew only three million pounds one foot high with each bufhel; but another at Wheal Vor mine drew fix millions.

Eftimation of the Force of Steam-Engines in Horfes' Power.—The method of expreffing the mechanical power of any machine by the weight of water or other matter which it will raife to a given height, in a certain period of time, or with a given quantity of fuel, is the moft unequivocal expreffion that can poffibly be obtained; but as fteam-engines are frequently fubftituted in the room of horfes, it has been cuftomary to calculate their mechanical energy in horfe-power, or to find the number of horfes which could perform the fame work. This, indeed, is a very vague expreffion of power, on account of the different degrees of ftrength which different horfes poffefs; but ftill, when we are told that a fteam-engine is equal to fixteen horfes, we have a more diftinct conception of its power, than when we are informed that it is capable of raifing a given number of pounds weight through a certain fpace in a certain time.

Prior to Mr. Watt's application of the fteam-engine to produce rotative motion, the great manufactories of the kingdom had their mill-work put in motion by the agency of water, of wind, or of horfes; and the latter had for many years been almoft exclufively employed in the breweries and diftilleries of the metropolis. It was, therefore, natural for thofe who wifhed to fubftitute the power of fteam for that of horfes, to ftate the number of thofe animals, to which the new power, under given conditions, ought to be equivalent; and it is probable that Meffrs. Watt and Boulton felt, that fuch a mode of comparifon would be more intelligible to common apprehenfions, than a more accurate and fcientific formula: it gave the power of an engine expreffed in numbers, of which the ordinary ftrength of a horfe is the unit. This, no doubt, is not in itfelf very exact, the unit being large, and fubject to confiderable variation. Relative to the purpofe for which it was ufed, it was, however, fufficiently correct; and on this, as on many fimilar occafions, a more minute meafurement would have been lefs ufeful. But to give this unit all the accuracy which can be defired, they have affumed, from the refult of experiments made with the ftrong horfes employed by the brewers in London, that the ftandard of a horfe's power is a force able to raife 32,000 lbs. one foot high in a minute: and this, no doubt, was meant to include an allowance of power fufficiently ample to cover the ufual variations of the ftrength of horfes, and of other circumftances that might affect the accuracy of the refult. In forming the eftimate juft mentioned, we think the power of a horfe is rated above the ordinary average, a circumftance which cannot be complained of by the public, as it tends to reprefent the advantage of the engines lefs than it will be found in real practice.

Dr. Brewfter, in his edition of Fergufon, ftates that Meffrs. Watt and Boulton fuppofe a horfe capable of raifing 32,000 lbs. avoirdupois one foot high in a minute; while Dr. Defaguliers makes it 27,500 lbs. and Mr. Smeaton only 22,916: if we divide, therefore, the number of pounds which any fteam-engine can raife one foot high in a minute by thefe three numbers, each quotient will reprefent the number of horfes to which the engine is equivalent, according to the eftimate of thefe different engineers. We will take, for example, an engine having a double-acting cylinder, on Mr. Watt's plan, 24 inches diameter, and which makes 20 ftrokes *per* minute, each ftroke being five feet long, and the force of fteam being equal to a preffure of 10 lbs. *per* fquare inch. Required the number of horfe-power of fuch an engine.

The fquare of the diameter of the cylinder being multiplied by the decimal number .7854, will give the area of the

piston: thus, $24 \times 24 = 576 \times .7854 = 452.4$ square inches, which are exposed to the pressure of the steam. Now if we multiply this area by 10 lbs., the pressure upon every square inch, we shall have $452.4 \times 10 = 4524$ lbs. the whole pressure upon the piston, or the weight which the engine is capable of raising with a certain velocity. To find this velocity, we say that the engine performs 20 double strokes, each of five feet long, in a minute; the piston must, therefore, move through $20 \times 5 \times 2 = 200$ feet in the same time; and, therefore, the power of the engine will be represented by 4524 lbs. avoirdupois, raised through 200 feet in a minute, or by $9\frac{1}{4}$ hogsheads of water, ale measure, raised through the same height in the same time. Now this is equivalent to $4524 \times 200 = 904{,}800$ lbs. or $9\frac{1}{4} \times 200 = 1848$ hogsheads raised through the height of one foot in a minute. This is reduced to the horse-power of Messrs. Boulton and Watt, by dividing by 32,000, their estimate of the horse-power: thus, $904800 \div 32000 = 28\frac{1}{4}$ horses.

According to Smeaton, $904800 \div 22916 = 39\frac{1}{2}$ horses.

According to Desaguliers, $904800 \div 27500 = 33$ horses.

In this calculation, it is supposed that the engine works only eight hours a-day, so that if it worked during the whole 24 hours, it would be equivalent to thrice the number of horses found by the preceding rule.

Other Constructions of Mr. Watt's Double Engine.—A great mass of matter must necessarily be put in rapid motion at every stroke of the reciprocating engine, and the motion must be stopped and returned at the end of the stroke. This is an evident disadvantage under which the double engine labours; for though all objection to the reciprocation, on account of the irregularity of motion, is done away by the application of a fly-wheel, the regularity thus attained is at the expence of the power, as we have shewn in the practical results of the large engines for pumping, and the engines for drawing from the mines. The most obvious improvement in this particular, is to lighten the mass of the great working beam, or to dispense with it altogether. The enormous strain exerted on its arms requires a proportional strength, and this requires a vast mass of matter, not less indeed (in an engine with a cylinder of 52 inches diameter) than three tons and a half, moving with the velocity of three feet in a second, which must be communicated in about half a second, so that this mass must be brought into motion from a state of rest, and must again be brought to rest, again into motion, and again to rest, to complete the period of a stroke. This consumes much power; and engineers have not been able to load an engine with more than 10 or 11 lbs. on the inch of the piston, and preserve a sufficient quantity of motion, so as to make 12 or 15 seven-feet strokes in a minute. Many attempts have been made to lessen this mass, by using a light framed wheel, or a light frame of carpentry, in place of a solid beam.

An example of this is shewn in the beam of Newcomen's engine (*Plate* II.), a method which was introduced by Mr. Smeaton; and another is shewn in Mr. Hornblower's (*Plate* V. *fig.* 1.) The form of this beam is such, that it would be stronger than a solid beam containing a great many times the quantity of timber, as there is scarcely any part of it which is exposed to a transverse strain, but every piece is either pushed or pulled in the direction of its length. The only evident improvement of which it admits, is to apply a strong tie-bolt along the whole length of the upper beam; because when tie-beams of wood are used, it is very difficult to connect the iron straps to the ends of them in such a manner, that they will not become loose in time. This is an objection to framed working beams, for although they are abundantly strong at first, yet, after being some time employed, the straps and bolts with which the wooden parts are connected, cut their way into the wood, and the framings become loose in the joints, and, without giving any warning, are liable to break to pieces in an instant. A solid massy simple beam of sufficient strength bends, and sensibly complains, (as the carpenters express it,) before it breaks. In all great engines, therefore, Mr. Watt at first employed such solid beams as were found the most durable, and least likely to break in a long course of work.

They were sometimes strengthened, in a very simple and effective manner, by placing a king-post perpendicular to the length of the beam, over its centre, and extending iron tie-bolts from the top of the king-post to the two extremities of the beam, so that the beam thus framed forms a triangle, of which the beam is the base, the king-post the perpendicular, and the iron ties the sides, meeting the perpendicular at the vertex of the triangle.

This was an expedient generally resorted to, when the beam was found to yield from a long continuance of the action. There is, perhaps, no example, except the mast of a ship, in which a piece of timber is exposed to such a severe strain as the beam of an engine, because it is necessarily made as small as possible; and it is relieved from the strain 15 or 20 times every minute, so that all the fibres are tried to the utmost: we accordingly see old beams, full of cracks lengthwise from the fibres, separating laterally, and after this the beam loses its strength.

Of late years, wooden beams have been altogether disused, and cast-iron beams substituted. We have already described the mode of making the beam for the largest engines, by two plates or flitches put together parallel, and leaving a space between them. For double engines, which are not of the very largest dimensions, it is usual to have the beam cast in one piece, of a form best adapted to give the greatest strength in the least weight. (See *Plate* IX. *Steam-Engine, Parallel Motions.*) The extremities of the beam are turned in a lathe to form cylindrical pins, and upon these pins are fitted sockets or pieces, which have other pins projecting from them to form the joints of the parallel motion and connecting rod; so that when the sockets are fixed on the ends of the beam, the pins will project from the beam in a direction perpendicular to its length, and parallel to its axis of motion. There are two pins thus projecting from each end of the beam, that is, one pin on each side of the socket: the two links of the parallel motion are fitted to the two projecting pins at one end, and the double joint of the connecting rod is fitted on the two pins at the other end of the beam. The advantage of this construction is, that the joints at the ends of the beam become universal joints, having liberty of motion in all directions: thus, in the direction in which the joints of the parallel motion and connecting rod are required to bend for the motion of the beam, as shewn in the figure, the motion will be upon the projecting pins of the sockets; but if, from the axis of the beam not being rightly placed, or from any other cause, a lateral flexure is required in the motion of the beam, the sockets of the joints will turn a little sideways upon the end of the beam, and allow the deviation, without any strain on the moving parts: were it not for this contrivance, the smallest possible deviation from the perpendicular direction of the cylinder would cause a great friction in the stuffing-box and joints. In Mr. Murray's best engines, the crank-pin is also jointed to the connecting rod by a universal joint. See *Plate* VIII. *fig.* 4.

All the joints of the parallel motion, the connecting rod,

and crank, in ſhort, all the moving joints of a double engine, muſt be fitted with braſs ſockets, which can be tightened round the pivots, ſo as to prevent all ſhake or looſeneſs, which, in an engine that works both in aſcending and deſcending, would be deſtructive of its action. The two great links of the parallel motion are each compoſed of a ſtrap or loop of iron, bent ſo as to make a double link, in the upper bend of which are two braſſes for the pivots at the end of the beam, and at the lower end are two others, for the pivots which project on each ſide from a ſocket, which is fixed on the top of the piſton-rod. The braſſes of the latter joint are held in by wedges, or croſs-keys, put through the two links at the lower end, ſo that by driving the wedges farther, the braſſes can be drawn tight at pleaſure. The two inſide braſſes, that is, the lower braſs of the upper joint, and the upper braſs of the lower joint, are kept extended to their proper diſtance by a piece of wood, or a light frame of iron, fitted in between them.

But we have not yet ſatisfactorily explained the action of the parallel motion. It is plain that the piſton-rod muſt aſcend and deſcend in a perpendicular right line, and alſo that the end of the beam muſt aſcend and deſcend in the arc of a circle. When the beam riſes into the poſition of *Plate* VI. from a horizontal one, it gives the piſton-rod a tendency to move from its perpendicular towards the centre of the beam, which muſt move towards it, was not the link, *b*, attached to the beam and piſton-rod by flexible joints; and while the lower end of the link, *b*, riſes, the end of the bar or lever *m*, dotted, which is moveable on a fixed centre *m*, alſo riſes at the ſame time, and the angle between *m* and *c* increaſes, and likewiſe the angle between *b* and *c* increaſes ſlowly; ſo that the vertex of the angle between *b* and *c* would move towards B, if the bar, *m*, was not confined to move round the fixed point or centre *m*, while the other end riſes along with the rod *c*. While *m*, therefore, riſes upon its centre, the adjoining bar, *d*, moves round the joint at its upper end, and draws *c*, and the lower end of *b*, from the centre of the beam, the angle between *d* and *c* increaſes, and the joint between *d* and *c* recedes from the centre of the beam; and as it cannot approach nearer to the joint between *b* and *c*, becauſe of the rod *c*, it keeps *a*, and the bottom of *b*, in a perpendicular poſition; ſo that whatever tendency the joint between *b* and *c* has to approach towards the centre of the beam by the increaſe of the angle between *b* and *c*, is corrected by an equal tendency of the lever, *m*, to draw the angle between *d* and *c* in a contrary direction; but as the beam, B, falls into a horizontal poſition, all theſe motions are reverſed. In adjuſting the parallel motion for work, when the piſton-rod, *a*, is found to rub moſt upon the ſide of the collar of the ſtuffing-box neareſt to *m*, the fixed centre point, *m*, muſt be ſhifted a little in the contrary direction, *viz.* to remove it nearer to the centre of the beam, and in an oppoſite direction if it is found to rub on the other ſide.

That the nature of this parallel joint may be better underſtood, it is proper to obſerve, that all the bars which have been mentioned are made double, which cannot be ſhewn in the figure, and that the two levers, *m*, *m*, are placed at a ſufficient diſtance aſunder to allow the links *b*, and the rods *c*, to deſcend between them.

Of late years, the framing for the ſupport of the engine has been wholly made of caſt-iron. A very good form is to make the ciſtern, L, of caſt-iron, all in one ſolid piece, and to fix the cylinder A upon it with four feet: a ſingle column is then erected upon the end of the ciſtern L, to ſupport the centre of the beam: the fly-wheel is ſupported by ſmall caſt-iron ſtandards riſing from the ground; and the centre of the lever *m*, of the parallel motion, is ſupported by a ſmall bracket or ſtandard erected from the flanch of the cylinder. By this arrangement, all the parts of the engine are ſo united, that they cannot deviate in the leaſt from their poſition, unleſs the parts are actually broken. An engine on this plan is fully deſcribed in the Britiſh Encyclopædia, vol. vi.

The engine repreſented in *Plate* VIII. *fig.* 4. is perhaps the moſt complete of all. It is of the form in which Meſſrs. Murray and Wood conſtruct their engines, when they are not of a very large power.

Steam-Engines without Beams.—Theſe have been made in a variety of forms. The ſimpleſt of all is to connect the piſton-rod at once with the connecting rod, and to place the crank over the centre of the cylinder: the piſton-rod muſt be guided by a parallel motion, or by ſliders. The objection to this is, that the fly-wheel becomes elevated to too great a height for the communication of its motion, except in very particular circumſtances, without ſhortening the connecting rod, which occaſions the irregularity of the action of the crank to be greater than that of our table, in which the length of the connecting rod is ſuppoſed to be ſix times that of the crank, or three times the ſtroke of the engine, as a ſhorter cannot be made to work well. There is alſo a difficulty in balancing the weight of the piſton-rod, connecting rod, and crank, and in giving motion to the air-pump. The balance-weight is uſually placed on the rim of the fly-wheel; and the air-pump is either worked by a ſecond ſmaller crank upon the axis of the fly-wheel, or by a ſhort beam.

Engines of this kind are frequently placed with the cylinder horizontally, and for ſmall engines this anſwers very well; but in large ones, the weight of the piſton acting always at one ſide wears the cylinder irregularly. Mr. Murray included this plan in his patent of 1799, which we have before mentioned, for producing the rotatory motion without a crank; and he propoſed to place rollers in the piſton to bear it up.

Steam-engines with horizontal cylinders are uſed with the greateſt advantage in ſteam-boats, as they can be made to lie low beneath the deck of the boat. Mr. Symington, we believe, firſt introduced this plan.

We have ſeen ſeveral engines working without a beam, in which the crank was placed immediately over the cylinder, and with the axis of the crank little more than its length above the top of the cylinder. For this purpoſe, the piſton-rod is prolonged upwards to a length of three or four times the ſtroke of the engine, and the top is guided in a groove, or by a friction-wheel: near the upper end of it is jointed the connecting rod, which deſcends down to the crank-pin, ſituated behind the rod, and as cloſe above the cylinder as it can turn round clear of its top. By this means, the aſcent and deſcent of the piſton-rod produce the rotation of the crank, the lateral deviation of the crank from the perpendicular being allowed for in the angle which the connecting rod makes with the prolonged piſton-rod.

In this way the crank muſt be placed behind the piſton-rod, or out of the line of it; but it is not then thought to work ſo well.

To remedy this the crank is made double, and the prolonged piſton-rod has an opening in it for the crank-pin to paſs through, and a connecting rod is placed on each ſide of the piſton-rod, ſo that it is worked between the two. It is evident that the opening through the piſton-rod muſt be a groove, equal in length to the ſtroke of the crank, ſo that the whole of the motion of the crank-pin, from one ſide to the other, can be admitted in the opening, without

influencing the piston-rod, except in its perpendicular ascent and descent.

The groove must be made wide, so that the pin cannot touch the sides of it. The pin is always retained in the middle of the groove by the connecting rods, of which there is one on each side, extending from the crank-pin to the top of the rod, which is prolonged in the line of the piston-rod, and is part of the frame forming the opening through which the crank-pin passes. It is evident, that in this way the opening cannot be a straight line, but must be formed to a portion of a circle, of which the centre is the joint that unites the connecting rods with the rod which prolongs the piston-rod, and in a line with it.

Another plan for applying the connecting rod immediately to the piston-rod, without the intervention of a working beam, is to have the axis of the crank placed immediately beneath the cylinder bottom, and a crank formed on it at each side: a cross-bar is placed upon the top of the piston-rod, long enough to reach over beyond the flanches of the cylinder; and from each end of it a connecting rod is suspended, the lower ends of which rods are jointed to the two cranks before-mentioned. This arrangement is, perhaps, the best of its kind, because the connecting rods are of a considerable length, without taking up any room.

Mr. Maudslay, of London, had a patent in 1807 for an engine of this kind, of which he has constructed a great number. *Plate* VIII. *fig.* 3. is a sketch of one of these. The specification states the invention to consist in reducing the number of the parts of the common steam-engine, and so arranging and connecting them, as to render it more compact and portable, every part being fixed to, and supported by, a strong frame of cast-iron, perfectly detached from the building in which it stands: it is not, therefore, liable to be put out of order by the sinking of the foundations. A is the cylinder, placed upon a frame of cast-iron plates B, B, which, at the same time that it elevates the cylinder to a sufficient height, forms the support for the axis of the fly-wheel D D. This axis has two cranks formed in it. E is one of the connecting rods, which, as before-mentioned, extends from those cranks up to the ends of the cross-bar, which is fixed at the top of the piston-rod, and which is guided in its ascent and descent by friction-wheels R, fitted upon it, and running in grooves N, N, formed in iron frames, which are placed in a perpendicular situation above the cylinder, and supported by a light iron framing O. Beneath the great frame, B, are placed two circular cisterns F, G, communicating by a pipe, which are for the condensing water: one has the cold-water pump in it, and the other contains the air-pump and condenser. These two pumps are worked alternately from the opposite ends of a short beam, H I, (*fig.* 5.) placed beneath the cylinder, and put in motion by a small crank, or excentric circle, which is formed on the axis of the cranks, in the middle between the two cranks, and acts in a groove or opening made in a projecting arm, K, of the beam, a small parallel motion being applied to that end of the beam which works the air-pump. Instead of valves for supplying steam to the cylinder, a single cock, with four passages in it at L, performs the office of all the four valves: the lever of the cock is worked by a rod of communication from a handle, which is moved up and down every stroke by the rod of the air-pump.

The condenser is a hollow cylinder, and the air-pump is placed within it, so that there is no necessity for a pipe of communication from the air-pump to the condenser: a small cistern, *r*, is fixed over the pump, to form the hot-well, and the discharge-valves of the pump are made in its lid or cover, and therefore in the bottom of the cistern.

A very ingenious method of converting the reciprocating motion of the piston-rod at once to a rotatory motion is represented in *Plate* IX. *fig.* 5. *Parallel Motions.* A toothed wheel, C, of a diameter equal to half the stroke of the engine, is made to roll round within a ring or fixed wheel A, having interior cogs, and being of a diameter equal to the whole stroke, or twice as great as the internal rolling-wheel C, which is carried round in a circular orbit, so as to work in the cogs of the ring, by having the crank-pin, R, for its centre of motion. By this means, every half turn of the crank will produce half a revolution of the centre of the small wheel in its orbit; and as it is all the time engaged by the cogs of the ring, it makes, during this motion, a whole revolution upon its own centre. The consequence of this is, that a point taken in the circumference of the small wheel, will travel up and down, across the centre of the interior ring, in every revolution of the small wheel in its orbit; that is, it will describe a right line, which is a diameter of the ring. A pin, F, being placed in a proper point of the circumference of the small wheel, and the top of the piston-rod being attached to it as it ascends and descends, will produce a rotation of the crank, upon the axis of which the fly-wheel is fixed.

This parallel motion is described in the article *Parallel* MOTION. It has been employed by Mr. Murray in many of his engines: the objection to it is, that the cogs in time grow loose, and it then makes a very noisy and unsteady motion.

Bell-Crank Engine.—This is a very compact form of the steam-engine, which Messrs. Boulton and Watt began to make soon after the expiration of their patent.

The cylinder is supported by brackets from the cast-iron condensing cistern, and is placed over one end of it. The beam is formed like a bell-crank, that is, a right-angled triangle, the centre of motion being at the right angle, and the axis of it is supported by bearings screwed to the cistern at the lower side: and at the end opposite to that upon which the cylinder is placed, the horizontal arm of the triangle forms the working arm of the beam, to the extremity of which the power of the cylinder is applied. At the upper end of the perpendicular arm the end of the connecting rod is jointed, and extends to the crank, which is supported in bearings screwed to the cistern at the same end at which the cylinder is placed, the centre of motion being at the same level with the top of the cistern; and beneath the cylinder, the hypothenuse of the triangle of the beam forms a brace to strengthen it. Two of these beams are used, and are applied on opposite sides of the cistern, upon the same axis of motion, and are united together by cross rods, so that they move together in the same manner as if they were one. There are, therefore, two connecting rods and two cranks; but they are formed upon one common axis of motion, which is prolonged, to carry the fly-wheel. To connect the piston-rod with the ends of the arms of the beam, or what we have called the base of the right-angled triangle, a rod is fixed upon the top of the piston-rod, across the same, at right angles; and to the two ends of this two rods are linked, which descend to the beam, and are jointed to it at the ends. By this means, the ascent and descent of the piston-rod produce a corresponding motion of the beam upon its centre of motion, and the upper end of the perpendicular arm moves backwards and forwards, and by means of the connecting rods turns the cranks. The perpendicular arms of the beam are shorter than the arms to which the cylinder-rods are attached, so that the motion of the connecting rods, and the

ſweep of the cranks, are leſs than in an engine where the arms of the beam are equal.

The rods which deſcend from the bar which is fixed acroſs the top of the piſton-rod to the ends of the beams, are of ſuch lengths, that the obliquity which is occaſioned by the circular motion of the ends of the beams is ſmall, and the engine does not require any parallel motion to keep the piſton-rod perpendicular. The ſame of the air-pump, which is placed in the middle of the ciſtern, and is worked by two rods jointed to the horizontal arms of the beams, at half the diſtance from the centre of motion at which the cylinder-rods are applied.

In theſe engines, valves are not uſed for admitting and taking away the ſteam from the cylinder; but to perform this office, a ſlider, invented by Mr. Murdoch, and repreſented in *Plate* VII. *fig*. 9, is uſed: the motion is communicated to the ſlider by an excentric wheel or rim, fixed on the fly-wheel. The bell-crank engine is very compact, and is well adapted for temporary uſe, as it ſtands wholly upon the ciſtern, and requires no fixing. We have ſeen it uſed in a ſteam-boat.

Different Methods of admitting Steam alternately into the Top and Bottom of the Cylinder.—The arrangement of the four valves invented by Mr. Watt has been deſcribed. This is now almoſt univerſally laid aſide, in favour of more ſimple contrivances, though we think there is not any method ſo complete in its action, or ſo durable. For large engines, four ſeparate ſpindle-valves are ſtill uſed; but the method of lifting them is changed, the ſpindle of one valve being formed like a tube, for the ſpindle of the other to paſs through. This plan is deſcribed in the ſpecification of Mr. Murray's patent of 1801, the ſame which was for the improved air-pump.

The arrangement of the pipes and paſſages is the ſame, and the valves are ſituated in the ſame places; but the boxes which contain them, inſtead of being ſquare, are cylindrical, and the ſpindles of the valves are placed concentric with the axis of the cylindrical box. The ſpindles of the two ſteam-valves are perforated through the centre, in the manner of tubes, and riſe through a ſtuffing-box in the top of the box, and levers are there applied to lift them, inſtead of the lever or ſector within the box, as deſcribed in the firſt engine. Through the tubular axis of the upper valves a ſmall rod is conducted, which forms the ſpindles of the lower valves; and this junction is made tight by a ſtuffing-box formed at the top of the tubes. The operation of the valves is in every reſpect the ſame as the former; the only difference is in the mode of communicating motion to them from the outſide, and at the top of the ſteam-box, both pair of valves being moved by rods through an opening in the lid of the box. See *Plate* VII. *figs*. 4 and 5.

This method is neat in its appearance, and anſwers equally well with the other when properly made, but it is not eaſy to make it like the other; for if the lid of the ſteam-box, when faſtened on, deviates in the ſmalleſt degree from the central poſition of the valve-ſpindle which paſſes through its ſtuffing-box, both the valves will be prevented from applying themſelves exactly to their ſeat. It is neceſſary for the two valve-ſeats, and the ſtuffing-box through the lid, to be made preciſely on a common centre, line, or axis; and for this purpoſe, the upper part of the cylindrical box which contains the valves is bored out correctly withinſide, and the conical ſockets in which the bell-metal ſeats for the valves are to be placed, are bored at the ſame time; then the lid of the box which has the ſtuffing-box in it, being turned in the lathe, with a ſmall projection beneath its flanch to drop into the top of the cylindrical box, it will be certain to apply itſelf exactly in the centre of the box, and alſo perpendicular, when it is ſcrewed faſt down in its place, becauſe the under ſurface of the lid, and the upper ſurface of the ſteam-box, have been accurately formed each of them concentric with, and perpendicular to, the axis of the valves; but it is neceſſary to uſe great caution in applying packing between theſe two ſurfaces, becauſe it will yield unequally, if the ſcrews at one ſide are ſcrewed down more forcibly than thoſe on the other ſide, and thus put the ſtuffing-box out of the perpendicular. To prevent this, Mr. Murray makes the lid of the box without any flanch, but it is exactly fitted into a ſmall receſs or rebate, formed for it all round at the top of the ſteam-box, by enlarging the diameter thereof a ſmall quantity, as ſhewn in *fig*. 15. There is no packing applied to the joint, and it is then certain that the lid of the box will come to its true place. To prevent leakage, an iron ring is applied all round with a packing beneath it to cover the joint; and this packing and ring being ſcrewed down by four ſcrews makes it tight, and at the ſame time keeps the lid faſt; but by releaſing the ring, the lid can be lifted out, and the valves with it, to repair them. Mr. Murray's patent was ſet aſide by a writ of *ſcire facias*, at the inſtance of Meſſrs. Boulton and Watt, who had previouſly practiſed ſome things contained in the patent; but we believe Mr. Murray was the firſt who made valves in the manner repreſented in the figure.

In ſmall engines, the machinery now employed for opening and ſhutting theſe four valves is different from Mr. Watt's original engine, and much more ſimple. The motion is given by a rotative motion from the main axis of the fly-wheel: a wheel is fixed on the axis of the fly-wheel, and communicates motion by other wheel-work to a horizontal axis *f* (*Plate* VII. *figs*. 4 and 5.), upon which are two excentric wheels, which open and ſhut the valves alternately. Each of the boxes may be conſidered as being divided into three compartments by the two valves, and the ſteam is always admitted into the top of the upper box, where the upper ſteam-valve is ſituated; its uſe is to admit ſteam which comes from the boiler through the ſteam-pipe into the middle compartment of the box, which is the paſſage, 14, communicating with the top of the cylinder. In this compartment is the upper condenſing valve *h*, which is moved by a rod paſſing through the rod or ſpindle of the upper ſteam-valve *g*: the valve *h* is for opening a paſſage from the top of the cylinder to the condenſer, through the exhauſting-pipe 13. In the ſame manner, the upper valve, *i*, of the lower box is called the lower ſteam-valve, and is for the purpoſe of admitting the ſteam which deſcends through the pipe, 12, into the bottom of the cylinder, below the piſton. The valve *k* is for connecting the bottom of the cylinder with the condenſer, and is therefore called the lower condenſing valve.

The two rods, L, M, connect the four valves together in pairs; thus, the rod L has an arm projecting from it at each end, one at its top, faſtened to the ſtem of the upper condenſing valve, and the lower ſteam-valve is connected with it at its bottom; it will conſequently, when it is lifted up by the excentric wheel, which is contained within an opening in the rod, open thoſe two valves, and, by cauſing a vacuum above the piſton, and a preſſure of ſteam beneath it, will force it upwards to the top of the cylinder.

The rod M is connected with the upper ſteam-valve at the top, and with the lower condenſing valve at the bottom. When it is lifted up by the excentric wheel, which works in an opening in the rod, it admits ſteam above the piſton, and cauſes a vacuum below, in which ſituation the piſton will deſcend. One of the rods which connect the valves muſt be allowed to deſcend by its weight an inſtant before the other is

lifted, otherwife the fteam will have a free paffage from the boiler to the condenfer, a fault which is called blowing through, but is an operation practifed every time at fetting the engine to work, after having been fome time at reft, for the purpofe of expelling the air from the condenfer. To blow through with this engine, all the four valves muft be opened at once, which is done by lifting up the two rods, L, M, both together.

Fig. 16. reprefents an ingenious form in which Mr. Murray makes the excentric movements for working the valves, fo that they fhall move all at once, and not have the liberty of returning until the proper time.

The excentric triangle, A B, has its fides formed by arcs of circles: the axis of motion is made to coincide exactly with one of the angles, A, and the arc, B, is defcribed from that centre. The excentric triangle is included within a parallel groove, C D, in an iron frame, in which it exactly fits, as in the figure. In this pofition, it is evident that the frame is immoveable; it cannot afcend, becaufe the circular part, B, bears againft the lower fide, D, of the groove; nor can it defcend, becaufe the angle, A, bears againft the middle of the upper fide C; at the fame time, the excentric triangle can move round a certain part of a revolution before the rod will be moved at all, and then it will rife all at once; fo that the middle of the lower fide of the groove, D, will bear againft the angle or centre of motion, A, and the upper fide, C, will be borne by the arc, B, of the excentric triangle.

Four-paffaged Cock.—Of late years, inftead of the four valves invented by Mr. Watt, cocks and flides have been much ufed for alternately admitting the fteam into the cylinder above and below the pifton: they have the advantages of fimplicity and cheapnefs, as one cock or flider is made to anfwer the purpofe of the four valves.

What is called the four-paffaged cock is the moft readily applied to practice. This is reprefented in *Plate* VII. *fig.* 6. which is the cylinder of an engine made by Mr. John Dickfon, who erected a great number exactly the fame: the cylinder and its pifton, with the lid and ftuffing-box for the rod, are evident from infpection. The cylinder has a flanch or projecting ring round it, a little below the middle, by which it is held in a jacket or cafe of caft-iron *c c c*, which is conftantly fupplied with fteam from the boiler by the pipe *e*: *f f* is a pipe, caft at the fame time with the cylinder, leading from the top of it, and by a crooked paffage to the cock E: *g g* is another fimilar paffage from the bottom of the cylinder to the cock, and entering it diametrically oppofite to the other paffage: *h* is an opening, bringing fteam from the jacket *c c c*, by means of a fhort pipe, not feen in the figure, being behind the cylinder, but caft at the fame time with it, and joining at bottom to the flanch, by which it is held in the jacket. The bore of this fhort pipe is, however, continued through the flanch, and opens into the jacket; and when they are fcrewed together, the fteam has free accefs from the boiler through the jacket into the fhort pipe, and from thence into the paffage *h*, which advances horizontally forwards, as reprefented by the dark circle *h*, *fig.* 6, and turns into the cock; the fhort pipe has a thin circular vane in it, turning upon a pivot to form the throttle-valve, as we have before defcribed.

When the fteam is not made to pafs through the jacket, the circular paffage, *h*, may be confidered as the continuation of the fteam-pipe coming immediately from the boiler; and then the throttle-valve is placed in fome part of the fame pipe: *p p* is the pipe conveying the fteam away from the cylinder to the condenfer, which is of the ordinary conftruction. K is a handle fixed upon a fpindle, on which is a rack, turning a cog-wheel upon the end of the cock E; this rack is partly feen in the drawing, but the pinion is concealed. There are two pins fixed upon the rod of the air-pump, which take the handle K, as they move up and down, and thus turn the cock a portion of a turn each time: there is alfo a lever fixed on the fpindle of the handle K, the ends of which ftop againft the ends of a crooked fteel-fpring fcrewed to the iron frame fupporting the bearings for the fpindle of the rack; fo that the motion allowed thereby to the handle, K, and the rack, will turn the cock one-fourth of a whole turn, but no more. N is a cock communicating (when open) from the jacket *c c c* to the pipe *p p*, and thereby to the condenfer, for the purpofe of blowing through at firft ftarting the engine. Now, fuppofe the fteam flowing through the fteam-pipe, *e*, from the boiler, it enters between the jacket, *c c c*, and the cylinder, paffes through the fhort pipe and throttle-valve into the opening *h*, thence through the crooked paffage in the cock E, to the pipe *f f*, leading to the top of the cylinder, thus caufing the pifton to defcend. The fteam in the lower part of the cylinder efcapes, by the pipe *g*, through the other paffage of the cock E, and by the pipe *p p*, into the condenfer. When the pifton arrives at the bottom of the cylinder, the pin on the air-pump rod carries down the handle, K, which, with its rack acting in the pinion on the end of the cock E, turns it into the pofition feen at *fig.* 7. The operation is now reverfed, the fteam enters from the jacket at *h*, through the cock E, and by the pipe *g*, into the bottom of the cylinder, forcing the pifton to the top; at the fame time the fteam contained above the pifton efcapes through the opening *f f*, and the cock E, by the pipe *p p*, into the condenfer. When the pin on the air-pump rod reaches the handle, K, in its afcent, it returns the cock to the pofition at *fig.* 6, when the operation is repeated.

Nothing can be more fimple, or appear more perfect, than this contrivance, which was originally ufed by Papin in his air-cylinders; and Leupold, in his Theatrum Machinarum Hydraulicarum, vol. ii. has fhewn the manner of its application to a high-preffure fteam-engine.

In practice it has feveral objections. The pipe leading from the top and bottom of the cylinder to the cock is fo much added to the volume of the cylinder, and the quantity of fteam which they contain muft be wafted every ftroke without any advantage; but in the four valves, there is no farther lofs than of the fmall quantity of fteam which is contained in the paffages 14 and 15, *Plate* VII. *fig.* 1. which are purpofely made as narrow as they can be to admit the fteam freely. Secondly: The paffages cannot conveniently be made large enough to admit a full fupply of fteam, though it fhould be underftood, that, in the other direction, they are three or four times as wide as they appear in the fection, *fig.* 6.

In thefe engines the fteam is always wire-drawn in paffing through the paffages; hence the fteam in the boiler muft be made ftronger than it is intended to be ufed in the cylinder, to which, however, there is no objection, as it gives it fomething of the expanfive action. Thirdly: Thefe cocks do not wear equally, becaufe there is much lefs furface expofed to friction in the part where the paffages are; and as the furface which is interpofed between the paffages is fo fmall, they leak immoderately from one paffage to the other, unlefs the fitting of the cock is perfect. For thefe reafons, the four-paffaged cocks have been confined to fmall engines, and principally thofe which work with high-preffure fteam, becaufe that will pafs through very fmall openings.

Mr. Bramah has made feveral fteam-engines, in which he employed a four-paffaged cock on a conftruction fomewhat different from the above. The fteam from the boiler is made to enter into a hollow at the large end of the cone

of the cock, and to pafs away to the condenfer by a paffage at the fmall end of the cone of the cock, which, by this means, is always preffed into its feat by the force of the fteam acting upon a furface equal to the fmall end of the cock, from which the preffure is relieved. This keeps the cock always tight; and to prevent the moveable part from being fixed faft by the preffure, the cone is made much more obtufe than ufual. The paffages for the fteam between the cock, and the top and bottom of the cylinder, are nearly the fame as in *fig.* 6. Mr. Bramah had a patent for this in 1802; and another improvement was, that he made the cock to turn continually the fame way round one-fourth at a time; by which means the fame effects are produced as by turning it backwards and forwards, but the wear is rendered more equable.

Mr. Maudflay has adopted in his engines a four-paffaged cock, in which the fteam is made to prefs the cone into its feat.

Sliding-Valves by Mr. Murray.—With a view of remedying the inconveniencies of the four-paffaged cock, the fame effect has been attained by a plate fliding upon a flat furface, in which the paffages are formed. A cylinder, with a flider upon this conftruction, is reprefented in *Plate* VII. *fig.* 8. It is ufed by Mr. Murray in fmall fteam-engines, and found to anfwer the purpofe extremely well, from the fimplicity of its conftruction, and its durability, but, above all, from not being fubject to wear or get out of order. A A reprefent the cylinder, inclofed in a caft-iron jacket, and furrounded with fteam: it is furnifhed with a pifton-lid, and ftuffing-box, for the rod to pafs through in the ufual manner; *a* is the paffage for the fteam to enter the top of the cylinder; and *b*, the paffage into the bottom, to admit fteam below the pifton. The fteam is conveyed from the boiler by the pipe B, paffes through the throttle-valve *c*, and into the fteam-box *d d*, from which it is diftributed to the cylinder by its different paffages, as required. This fteam-box is fcrewed by a flanch againft the flat furface of a pipe D, extending from the top of the cylinder to the bottom, and attached by dove-tailed joints to the two necks, *a*, *b*, of the cylinder. In the flat furface of the pipe D, there are three openings, *m*, *n*, *o*: the upper one, *m*, communicates with the top of the cylinder, through the paffage *a*; the middle opening, *n*, communicates with the condenfer by paffing out fideways to the eduction-pipe, as at the dark circle at *p*; and the lower opening, *o*, communicates with the bottom of the cylinder by the paffage *b*: *r* is the flider, made in the form of a box or cover, and ground round its edges, fo as to fit exactly flat againft the furface of the fteam-pipe D, in which the three openings are made, and which is ground alfo. This flide is moved up and down by the fmall fector *s*, acting in the teeth of a rack, fixed to the back of the flide. The fpindle of the fector paffes through a ftuffing-box in the fide of the fteam-box, and is moved on the outfide by an excentric wheel on the axis of the fly-wheel. The motion of the flider *r*, up and down, either connects the openings of the two paffages *m* and *n*, or the two openings *n* and *o*. In the drawing, it is reprefented as connecting the upper paffage *m* with *n*, which leads to the condenfer, at the fame time leaving the opening *o* uncovered, to receive the fteam from the fteam-box; confequently the fteam enters below the pifton, through the neck *b*, caufing it to rife, and efcapes from the top of the cylinder through the neck *a*; and by the connection of the opening *m* with *n*, it paffes out at *p* into the condenfer. Now if the flide is moved down, by turning the fector *s*, fo that the lower paffage *o* is connected with *n*, which leads to the condenfer, the top opening *m* will be open to the fteam-box, and the fteam will enter at the top of the cylinder, and caufe the pifton to defcend, while the fteam in the bottom of the cylinder will rufh through the opening *b*, and by the connection of the paffage *o* with *n*, it will pafs into the condenfer. In this manner, by alternately moving the flide up and down, this action is repeated, and the engine kept going.

In the figure of Mr. Murray's fmall engine (*Plate* VIII. *fig.* 4.) the excentric circle B is plainly feen upon the axis of the fly-wheel; it operates exactly the fame as a fhort crank, and has an iron frame or collar embracing it. By this a motion backwards and forwards is communicated by the rod B S to an axis, upon which are levers, giving motion to the lever of the fector, which moves the fliding-valve. The whole of the engine is upon an excellent conftruction: the air-pump is worked by the rod R, at the outer end of the beam.

In 1799, Mr. William Murdoch of Redruth, in Cornwall, obtained a patent for feveral improvements in fteam-engines, amongft which is a fimple conftruction of the fteam-valve, or contrivance by which the fteam is diftributed to the cylinder, or withdrawn from it at the proper period.

This contrivance is a fliding-valve, which performs all the offices of the four valves which we have defcribed for the double engine. Mr. Murdoch's patent has been adopted by Meffrs. Watt and Boulton in moft of their fmall engines, for many years paft; and they have lately, with fome alterations, introduced it into large engines. In *Plate* VII. *fig.* 9, A A is the fteam-cylinder of the engine; B, the pifton, and C, the pifton-rod; D is the upper opening or fteam-way into the cylinder; F is the fteam-cafe: in this is applied the fliding-tube, which performs the office of all the four fteam-valves in the manner following. G G is a femicylindrical fteam-pipe, (but which may be cylindric, triangular, or of any convenient form,) communicating with the fteam-cylinder both at its upper and lower openings, and firmly fixed or connected to the fteam-cafe, or with the cylinder itfelf, where no fteam-cafe is ufed.

This tube has an opening, H, on its fide, with a regulating valve for the admiffion of fteam from the boiler; and another opening, I, at bottom, which leads to the condenfer. At the top it is covered with a plate T, having a hole and ftuffing-box to admit the fliding-rod K, which is jointed to, or connected with, an inner moveable pipe or tube L M, open at both ends. To one fide of the fliding-tube are affixed the folid plates or valves L, M, intended to flide upon the plates at D and E, and occafionally to cover and uncover the upper and lower openings D and E of the cylinder. Oppofite to thefe plates the remaining circumference of the tube, L M, is furnifhed with projections or flanches of brafs, or other metal, with an interftice between them, to receive a packing of hemp, or other proper fubftance, which will permit the tube, L M, to move up and down, fteam-tight, in the fixed tube G G. There are openings provided in the fteam-pipe G G, which are fhut with plugs or plates, fcrewed or otherwife fixed to it, which may be removed to repair the packing.

When the fliding-tube, L M, is in the pofition fhewn in the figure, the fteam enters through the fteam-pipe H, and filling the interftices between the fteam-tube G G, and the fliding-tube L M, paffes into the cylinder at the upper opening D. As the lower opening, E, is open to the condenfer, a vacuum will be formed withinfide the fliding-tube L, and alfo below the pifton, through the paffage E, which is uncovered by the rife of the fliding-rod. In confequence, the pifton defcends; and when it has got near the bottom

of the cylinder, a bracket, attached to the top of the piston-rod C, strikes a projection upon the sliding-rod K, and causes the tube, L M, to descend a small quantity in the steam-pipe G. The sliding parts, L, M, by this motion, slide past the openings D and E of the cylinder, so as to be beneath them; and the steam, which is above the piston, issues at the upper opening, and passes down the inside of the tube L M, into the condenser. At the same time, the steam continuing to pass from the boiler through the pipe H, and the interstice between the steam-pipe and the sliding-pipe, enters the cylinder by the lower opening E, and forces up the piston and piston-rod, with its bracket, which, near the end of the ascending stroke, encounters another projection of the sliding-rod K, and raises the tube, L M, into its former position of the figure. The operations are then repeated. This is the plan used in Messrs. Watt and Boulton's bell-crank engine, and it is very good, because no steam is lost, as in all other constructions, where only one cock or slider is used.

If the sliding-plates, where they apply together, are made of steel, and hardened, they then wear extremely well. In some of Messrs. Watt and Boulton's latest engines, they have used similar sliders for large engines; but, in this case, they make the two sliders separate, being moved only by a rod of communication: because, if they were applied to a strong moving pipe, there would not be so great a certainty of their complete action, as the least deviation of the two sliders at the top and bottom of the cylinder would cause a great leakage.

There are many other methods of distributing the steam alternately to the top and bottom of the cylinder; but as we have described those which are brought to such a degree of perfection as to be commonly used, it is unnecessary to pursue the subject any farther.

Regulation of the Velocity of an Engine.—This is a matter of considerable importance. The most common method, as we have noticed, is by the governor or revolving pendulum; but there are others which, in particular circumstances, are very applicable. One is to have a small pump worked by the engine, and raising up water into a cistern, from which it runs out again in a constant stream. By this means, the water will accumulate and rise in the cistern, if the engine works rapidly, so as to pump more water into the cistern than will flow out of it in the same time; and, on the other hand, the surface of the water will sink in the cistern, if the engine works slowly; and a float being placed in the cistern, and connected with a wire to the throttle-valve, will regulate the motion of the engine. See Regulator.

In 1805, Mr. Job Rider obtained a patent for improvements in the steam-engine. These improvements consist, first, in lining the steam-cylinder with a soft metal, of a sufficient thickness to admit of finishing the inside of the cylinder of such metal, by drawing, boring, or otherwise; secondly, in applying a hollow piston-rod, answering the purpose of an eduction-pipe; thirdly, in the order of opening and shutting the valves; and fourthly, in regulating the speed of the engine by a pendulum. The nature of this latter contrivance is very ingenious, and may perhaps be understood from the following description. Upon an horizontal arbor, which we will denominate the main arbor, are placed three wheels, a drum or barrel, and a pinion: one of these wheels, that is to say, the main wheel, is fitted by means of a socket upon the main arbor, so as to turn round upon that arbor, and has teeth both upon the exterior and interior periphery of its rim. Within the circle of the interior cogs of this wheel a pinion is fixed to the arbor, its diameter being one-third of the interior diameter of the main wheel; and this pinion has teeth surrounding its convex surface. The moveable barrel turns freely upon the main arbor; its diameter is rather less than the exterior diameter of the main wheel, and it carries a cord, with a weight hanging at its end, acting like a clock-weight. Besides this, the ends of the barrel are pierced with two orifices, each at about half the exterior radius of the main wheel from the arbor; these holes serving as bushes or pivot-holes, wherein an arbor turns, carrying a wheel, of which the diameter and number of teeth are equal to those of the pinion: the latter wheel may be called the barrel-pinion; its teeth work in the teeth of the pinion, and also in the interior teeth of the main wheel. By these means, the barrel may be turned round upon the main arbor, while the arbor itself is turned by the pinion, which is acted upon by the barrel-pinion, at the same time that this pinion acts upon the interior teeth of the main wheel. The external teeth of the main wheel turn the pinion of a scapement-wheel and pallets, nearly similar to those in Graham's dead-beat. Near one end of the main arbor there is a ratchet-wheel, and wheel and click; and near the other end a wheel, which is acted upon by an endless screw upon a horizontal shaft, worked by the general operation of the steam-engine.

This arrangement serves to regulate the rate of the engine's motion; for the turning of the worm-wheel, by the general motion of the engine, causes the weight to be raised which hangs to the cord that winds upon the barrel; and this weight is connected to one end of a lever, the other end of which is attached to the steam-valve in such a manner, that the degree of opening of that valve depends upon the altitude to which the weight is raised. The aperture of this valve is formed like an inverted cone; and while this valve shuts and opens twice at every stroke, the lever does not prevent such opening and shutting, but merely limits the extent of the opening by the springing up of a rod connected with it. By this contrivance it happens, that when the weight is highest, the valve is least opened; and when the weight is lowest, the valve is most opened. Hence it is evident, that should the engine wind up the weight, by turning the worm faster than the pendulum permits it to descend by the turning of the barrel, the aperture of the valve will be contracted; and *vice versâ*. Little power is lost by these means, and the speed of the engine can be accurately regulated by properly adjusting the length of the pendulum, and the numbers of teeth in the wheels and pinions. As to the ratchet-wheel and click, their sole use is to prevent the weight from drawing the line off the barrel, when the worm-wheel is thrown out of gear. We have not had an opportunity of seeing one of these machines at work, but think it would operate very well.

Mr. Cartwright's Engine.—In giving the history of Mr. Watt's inventions, we mentioned that the condensation by external cold was one of his first ideas, and given up, because he found it better to employ injection. We have also described his single engine, in which the piston rises in vacuo. In 1797, Mr. Cartwright took out a patent for improvements in the construction of steam-engines, in which the condensation is performed by the application of cold to the external surface of the vessel containing the steam.

The manner Mr. Cartwright effects this is by admitting the steam between two metal cylinders, lying one within the other, and having cold water flowing through the inner one, and surrounding the outer one. By these means, a very thin body of steam is exposed to the greatest possible surface of cold metal. By means of a valve in the piston, there is a constant communication at all times between the condenser and the cylinder, either above or below the pis-

ton; so that whether it ascends or descends, the condensation is always taking place, in the same manner as Mr. Watt's engines, where the piston rises in vacuo. But what was probably esteemed one of the most important circumstances attending the mode of condensation, was the opportunity it affords of substituting ardent spirit, either wholly or in part, in the place of water, for working the engine. For as the fluid, with which it is worked, is made to circulate through the engine without mixture or diminution, the using alcohol, after the first supply, would be attended with no very great expence; on the contrary, the advantage was expected to be great, even equal to the saving of half the fuel. If, indeed, the engine could be applied, as Mr. Cartwright occasionally purposed, both as a mechanical power and as a still at the same time, the whole fuel would be saved.

Mr. Cartwright has been very attentive in simplifying all the other parts of the engine, his engine having only two valves, and those are as nearly self-acting as may be: in consequence, the engine is rendered applicable to purposes requiring only a small power, and for which any other engine would be too complicated and expensive. See a figure of Mr. Cartwright's engine, *Plate* V. *fig.* 8, where *a* is the cylinder, which is supplied with steam from the boiler through the pipe *b*; *c* is the piston in the act of going up; *d* is the eduction-pipe that conducts the steam into the condenser *w*, which consists of two cylinders, one within the other, leaving a small space between them, into which the steam is admitted; while the inner cylinder is filled with cold water, and also the external cylinder surrounded by the same; so that, by this means, a very large surface of steam is exposed to the cold of the water, though no water is suffered to come in actual contact with it.

To the bottom of the piston *c* is attached a rod, with another piston *e*, working in the barrel *d*, which is in reality the air-pump of the engine, and has a pipe, *f*, to the condenser. When the piston *c* arrives at the bottom of the cylinder, a valve, *r*, which is in the piston is opened, by its tail pressing against the bottom of the cylinder, which opens the communication from above the piston to the condenser, while the spring *k*, fixed to the rod of the piston, presses down the tail, and shuts the steam-valve *t*, which admits the steam from the boiler. The steam therefore within the cylinder, both above and below the piston, being condensed, runs through the lower pipe, *f*, to the air-pump, and the piston, being relieved from all pressure, is drawn up in the cylinder by the fly-wheel. The piston *e* of the air-pump arriving at the top of the barrel, in which it works at the same time with the working piston *c*, draws the air from the condenser, and on its return at the next stroke, presses upon the condensed water, shuts the valve *f*, and forces the water up the pipe *g*, into the box *h*: the air which is disengaged from the water rises to the top of the box, and by its elasticity forces the water through the pipe *i*, which carries it back again to the boiler. When the air accumulates in the box to such a degree as to depress the water, the ball cock falls with it, and opens a valve in the top of the box, which suffers some of the air to escape.

When the piston arrives at the top of the cylinder, it presses up the steam-valve *t*, which admits the steam again from the boiler, to force it down as before; and the valve, *r*, in the piston shuts by pressing up beneath the top of the cylinder. The pressure of the steam is now above the piston, and a vacuum beneath; the piston therefore descends, and when at the bottom, shuts the steam-valve *t*, and opens the valve, *r*, in the piston.

When all the steam in the upper part of the cylinder is condensed, the motion of the fly attached to the machine brings the piston up again, its valves now remaining shut by their weight.

l and *m* are two cranks, upon whose axes are two equal cog-wheels working in each other, for the purpose of converting the perpendicular motion of the piston-rod into a rotatory motion for working the machinery attached to it.

As it is evident, from its construction, that the whole of the steam is brought back again into the boiler, it affords the means of employing ardent spirit instead of water, and thus saving a great deal of fuel.

Cartwright's Metallic Piston.—The most valuable part of this engine is in the construction of the piston, which Mr. C. made wholly of metal, so as by means of springs to fit the cylinder very exactly.

This not only saves the expence and trouble of packing, which must be frequently renewed in all other engines, but also a great deal of steam, on account of the more accurate fitting of the piston. This piston is made in the following manner: Two metal rings are ground, by means well known to good mechanics, into the cylinder, so as to fit it as perfectly as art and industry can make them; that is so well, that no steam can pass between them and the cylinder: their upper and under sides are also ground perfectly flat, and applied one upon the other. Though not absolutely necessary, for greater security two other rings are fitted to the inside of these. On the upper rings is placed a plate of metal, also ground perfectly flat, and of such a diameter as almost to fit the cylinder. A similar flat plate is placed below the under ring; and the two plates, with the rings between, are attached firmly to each other by means of the piston-rod that passes through them, and they thus form a shell, in which the other rings are contained.

It is plain then, supposing neither the outside rings nor the cylinder are able to wear one another, that such a piston would remain steam-tight; but as constant friction must inevitably tend to enlarge the cylinder, and diminish the diameter of the rings, the piston, after some time, would cease to fit, if a contrivance had not been made to remedy the evil. The rings are each of them cut into three pieces, and in cutting them, such a portion of the metal is taken away as to leave room to introduce, between two of the pieces, a spring in form of the letter V, the open end of which is placed outwards, almost close to the circumference; by which means the two pieces against which the two sides of the spring act are pressed, in the direction of the circumference, against the ends of the third piece; so that the three pieces are thus kept so uniformly in contact with the cylinder, that the longer the machine is worked the better the rings must fit.

To prevent steam passing through the cuts in the rings, the solid parts of the upper rings are made to fall upon the divisions and springs of the under ones, so as to form a break joint.

The stuffing-box round the piston-rod was proposed to be done in the same manner.

The metallic piston has been found advantageous, and Mr. Woolf uses it in his engines, which is the greatest trial of a piston, because of the rarity of the steam. *Plate* VII. *figs.* 10 and 11, represent a piston of a four-horse engine, which was made by Messrs. Lloyd and Ostel. A is the piston-rod, and B C C the solid metal of the piston, firmly fitted and keyed to it: the lower edge, C, of the plate, B, is made very nearly to fit to the cylinder; but for the actual fitting, dependence is placed on the four rings, D, fitted one upon another, and each divided into four segments, as shewn by *fig.* 10. The interior surface of these rings is made rather conical, and a second set of smaller rings, E, is accurately

fitted withinfide of them. Thefe rings are divided, like the former, each into four fegments, and the fprings are applied behind them, as fhewn in *fig.* 10, in a better manner than the original, which were like the letter V. E E is the cover-plate, which is fcrewed on over all the fegments, to confine them: it preffes down the interior rings into the exterior, and the contact between them being by a conical furface, the effect is to fpread the outer rings a fmall quantity, and enlarge them till they exactly fill the cylinder. The dark mark beneath the lowermoft interior ring E, is a piece of felt or pafteboard, which fuftains the rings, and prevents them from defcending, except when the fcrews are tightened, or the rings would expand with too much force into the cylinder.

Woolf's improved Pifton.—The common method of packing the pifton of a fteam-engine with hemp, will be fo well underftood after what we have faid, that a particular defcription of it in this place is not neceffary; fuffice it to fay, that the hollow part round the pifton is filled with rounds of hemp, loofely twifted into a foft rope, which is preffed into a pretty compact form by a ring, and worked down by fcrews diftributed round the ring, which work into the body of the pifton; by this means the packing is made to fill the diameter of the cylinder pretty clofely, and to prevent, while the packing remains found, any fteam from paffing between the pifton and the cylinder. In the ufual method, whenever the pifton, by continued working, becomes too eafy, and fo occafions a wafte of fteam, it is neceffary to take off the top of the cylinder, even when frefh hemp or packing is not wanted, merely to get at the fcrews, which ferve to force the upper ring nearer to the bottom of the pifton, by which means the packing is forced outwards againft the fide of the cylinder.

This being heavy laborious work, it is generally deferred, by the man that attends the engine, as long as the engine can poffibly be made to work without taking this trouble; and in confequence of this neglect, a great and unneceffary wafte of fteam is occafioned, and a wafte of fuel in proportion.

Mr. Woolf's improvement on the pifton is fuch as to enable the engine-man to tighten the pifton, without the neceffity of taking off the cover of the cylinder, except when new packing becomes neceffary. He accomplifhes this by either of the two following methods. He faftens on the head of each of the fcrews a fmall ..g-wheel, *c, c, c, c,* (*Plate* VII. *figs.* 12 and 13.) which wheels are all connected with each other by means of a central wheel *d d*, which works loofe upon the pifton-rod in fuch a manner, that if any one of the fmall wheels and its fcrew be turned, it turns the central wheel, and the latter turns all the other three wheels and fcrews. That one which is to be firft turned is furnifhed with a projecting fquare head *f*, which rifes up into a recefs in the cover of the cylinder. This recefs is furmounted by a cap or bonnet, which being eafily taken off, and as eafily put again in its place, there is little difficulty in fcrewing down the packing at any time, by applying a key to the fquare head of this fcrew. The parts are fo clearly expreffed in the plates, that no farther defcription is neceffary to make any perfon comprehend it.

Mr. Woolf contrived another method for fmall piftons, which is fimilar in principle, but a little different in conftruction. Inftead of having feveral fcrews, all worked down by one motion, there is in this but one fcrew, and that one is cut upon the pifton-rod itfelf; on this is placed a wheel of a convenient diameter, the centre of which is furnifhed with a female-fcrew. This wheel is turned round, *i. e.* fcrewed down by means of a pinion, which is furnifhed with a fquare projecting head, rifing into a recefs of the kind already defcribed. The upper ring of the pifton is prevented from turning with the wheel by means of two fteady pins.

High-Preffure Steam-Engine.—The operation of the high-preffure fteam-engine is effected folely by the expanfive force of fteam, which is not condenfed in the manner of the atmofpheric or Watt's engine. The fteam being raifed in the boiler, and heated far beyond the boiling point, is made to acquire a great expanfive force, and exert an immenfe preffure to efcape from any veffel in which it is confined, even as great as four or five times the preffure of the atmofphere. This fteam being allowed to enter into one end of a cylinder, while the other end of the fame communicates with the open air, it will exert a force upon the pifton of the cylinder, and move it from one end to the other. This is the principle of the high-preffure engine, which has been much introduced of late, on account of fome advantages which it poffeffes in particular fituations over other engines: firft, from the fimplicity of its conftruction and cheapnefs; fecondly, the fmall fpace which it occupies; thirdly, its requiring no condenfing water, which in fome fituations is very difficult to procure, and in one inftance is altogether impracticable, *viz.* for drawing of carriages, for which purpofe this engine has been fuccefsfully ufed. To fet againft thefe advantages, the high-preffure engines are extremely liable to blow up, if not attended very carefully, for they are frequently worked with a preffure of from fixty to eighty pounds on the fquare inch. Thefe engines require a greater quantity of coals, in proportion to the force exerted, than the engines of Mr. Watt, and confequently are not worked with advantage in a fituation where coals are dear.

The firft application of high-preffure fteam to an engine, is what we find defcribed in 1724, by Leupold, in his Theatrum Machinarum Hydraulicarum, vol. ii. p. 93. He afcribes the invention to Papin, on account of his having given him the idea of applying the expanfive force of fteam for the purpofe of raifing water, and alfo becaufe he took the conftruction of the four-paffaged cock, to communicate alternately with two cylinders, from Papin's air-machine, which has been defcribed in the former part of this article. The engine defcribed by Leupold confifts of two fingle cylinders, placed at fome diftance from each other, with a pifton fitted to each, and applied to two feparate beams, which at the oppofite ends work two forcing-pumps. Between the two cylinders is the four-paffaged cock, the fame as defcribed in *Plate* VII. *Steam-Engine, fig.* 6, for admitting the fteam from the boiler alternately into the bottom of each cylinder, or allowing it to efcape from the cylinders into the air. The boiler is fituated beneath the two cylinders, and communicates with the cock by a fhort upright pipe. The action of this engine is very fimple: the fteam being raifed very ftrong in the boiler, is allowed to enter through the cock into the bottom of one of the cylinders, at the fame time that the air or fteam efcapes from the bottom of the other, through the other paffage of the cock into the open air. In this way, the preffure of the fteam caufes the afcent of the firft-mentioned pifton, and the other defcends by its counter-weight. By turning the cock round one-fourth, the operation is reverfed, fo that the fteam enters the bottom of the fecond cylinder, and the fteam which was contained in the firft efcapes through the paffage of the cock into the air.

The next propofal for a high-preffure engine is Mr. Watt's patent of 1769. See the fourth particular of his fpecification, which we have given, but we do not know that he ever practifed it, finding his own invention fo much fuperior.

The high-preffure engines at prefent in ufe were introduced by Mr. Trevethick, in conjunction with Mr. Vivian, who obtained a patent for the fame in 1802: this was prin-

cipally for their application of the engine to the purpofe of driving of carriages upon rail-roads.

This engine containing no material parts which are not ufed in other engines, and before defcribed, it may be explained without a drawing. The boiler confifts of a large cylinder of caft iron, made very ftrong, and placed with its axis horizontally upon fhort feet or pillars of caft iron: the boiler has a flanch at one of its ends, to fcrew on the end or cover, which has the requifite openings for the fire-door, the man-hole, the exit for the fmoke, and the gauge-cocks. The fire is contained within the boiler, in a cylindrical tube of wrought iron, which is furrounded with water on all fides, in the fame manner as the fire in Mr. Smeaton's portable engines, of which we have given the defcription; but there is a little difference in the application: one end of this tube is flanched to the end or cover of the boiler, and is divided into two parts, by having the fire-grate extended acrofs it: the fire-door clofes the opening in the upper half, which is the fire-place, the lower half forming the afh-pit: the tube extends nearly to the end of the boiler, where it is reduced in fize, then doubles, and returns back in a direction parallel to the firft tube or fire-place to form the flue or chimney, till it arrives at the end or cover of the boiler, through which it paffes at the fide of the fire-door, and a flue is then conducted from it into the chimney, to carry off the fmoke.

At the part where the flue enters the chimney is a fmall door, to remove any foot that may have accumulated. On the top of the boiler is a fafety-valve, kept down by a lever and weight, to allow the fteam to efcape in cafe it becomes fo ftrong as to endanger the burfting of the boiler. The fteam-cylinder ftands in a perpendicular direction, and is inclofed within the boiler, except a few inches of its upper end, at which the four-paffaged cock is fituated, and the flanch which fcrews on the lid, with the ftuffing box for the pifton-rod to pafs through. The boiler has a projecting neck, into which the cylinder is received, and it is faftened in its place by a flanch round the upper end of the neck of the boiler, which is united by fcrews to a flanch projecting from the cylinder at about one-third from its top flanch. The upper end of the pifton-rod is faftened to the middle of a crofs-bar, which is placed in a direction at right angles to the length of the boiler, and guided in its afcending and defcending vertical motion, by fliding upon two perpendicular iron rods, fixed to the boiler, parallel to each other, being connected together at top, and firmly fupported there by two diagonal ftays, extending from the other end of the boiler, and fecured to the flanch, which fcrews on the end of the boiler. At the ends of the crofs-bar of the pifton-rod the two connecting rods are jointed, and the lower ends of them are connected with two cranks, fixed upon an axis, extending acrofs beneath the boiler, and under the centre of the cylinder: the axis is fupported in bearings made in the legs which fupport the boiler, and the fly-wheel is fixed in it. One of the cranks is formed by a pin which is fixed into the arm of the fly-wheel, at the fame radius as the oppofite crank. The fly-wheel is fituated clofe to the fide of the boiler, and the pin for the other crank is fixed into the arm of a large cog-wheel, fixed on the axis of the fly-wheel, at the oppofite fide of the boiler. This cog-wheel communicates the power of the engine to other cog-wheels. As the pifton is alternately forced up and down by the preffure of the fteam, it carries the crofs-bar with it, and by the connecting rod turns the two cranks, together with the fly-wheel and cog-wheel.

It now remains to fhew the means by which the fteam is brought to act alternately on different fides of the pifton. On one fide of the cylinder, juft above the flanch which fixes it into the boiler, and beneath the top flanch, which faftens down its lid, is a protuberance of caft iron, to contain the four paffages and the cock, fimilar to that fhewn in *figs*. 6 and 7. One paffage rifes directly from the boiler, and brings fteam to the cock at one fide, to be diftributed either to the top or bottom of the cylinder, according to the pofition in which the cock ftands. A fecond paffage rifes from the upper fide of the cock, and proceeds to the top of the cylinder, for admitting fteam above the pifton. The third paffage from the under fide of the cock connects with the bottom of the cylinder by a pipe caft clofe to the fide thereof, and defcending to the bottom. The fourth paffage from the cock is on the oppofite fide to where the fteam enters from the boiler, and this paffage is open to the wafte-pipe, which carries the fteam into the external air, and allows it to efcape after it has paffed through the engine. Now fuppofe the paffage leading to the top of the cylinder, and that one which brings fteam, are from the boiler to be connected with the cock, and the paffage from the bottom of the cylinder to be connected with the wafte-pipe, the fteam will enter above the pifton, and force it down, at the fame time that the fteam in the bottom of the cylinder will efcape by the connection of the wafte-pipe with the open air.

When the pifton arrives at the bottom of the ftroke, the cock is turned one quarter round, by means of a rod jointed to the crofs-bar of the pifton-rod, and defcending perpendicularly, being guided at bottom by paffing through a piece of iron fcrewed to the flanch of the cylinder: this rod has two pins projecting from it, which move the handle of the cock up and down alternately; by this the cock is turned on the completion of the defcending ftroke, fo that the paffage to the bottom of the cylinder is connected with the boiler, and that from the top with the open air: the fteam in confequence enters below the pifton, and forces it up, paffing out from the upper part of the cylinder into the open air at the fame time. In this manner the motion of the engine is kept up by the pins alternately turning the cock, firft at the top of the ftroke, and then at the bottom.

The boiler is fupplied with water, as faft as it evaporates, by means of a fmall force-pump worked by the engine; but as it would be a great lofs of heat to inject cold water at once into the boiler, it is firft rendered nearly or quite boiling by a very fimple contrivance. The wafte-pipe, which conveys the fteam away from the cylinder after having performed its office, is inclofed within an external pipe or jacket, leaving a fpace of about an inch all round; through this fpace the cold water is forced to enter at one end by the fmall force-pump, and the boiler is fupplied with water by a branch from its other extremity. By thus carrying the water fome diftance in contact with the hot wafte-pipe, through which the fteam paffes, it is heated, and a confiderable quantity of heat is faved, which would otherwife be loft.

The velocity of the engine is regulated, or its motion can be entirely ftopt, if required, by a cock fituated in the firft paffage from the boiler to the four-paffaged cock, fo as to regulate the paffage between the boiler and the cock. The handle of this cock may be connected with a governor, fimilar to thofe ufed in other engines. The conftruction of the four paffages and cock is exactly fimilar to what is reprefented in *fig*. 6. *Plate* VII., except that it is placed near the top of the cylinder, becaufe all the lower part of the cylinder is contained in the boiler, and alfo that the axis of the cock is directed to the centre of the cylder. High-preffure engines have been fometimes made with beams and parallel levers; but more frequently the cylinders have been placed horizontally, and the pifton-rod jointed at once to the connecting rod.

Several very terrible accidents have occurred from the

bursting of high-pressure boilers, either from their being made too weak to resist the force they are intended to bear, or from some mismanagement, as loading the safety-valve too much. Some years ago, an engine that was employed to drain water from the tide-mills, while building between Woolwich and Greenwich, was blown up by overloading the safety-valve, when several people were killed. Many provisions have been made to guard against these accidents by Mr. Trevethick, who first brought the high-pressure engines into use: at first he proposed inclosing the safety-valve in such a manner, that no one could get access to it to increase the load beyond what was intended to be employed. Secondly, he drilled a hole in the boiler, which he plugged up with lead, at such a height from the bottom, that the boiler could never boil dry without exposing the lead to be melted, and consequently making an opening for the steam to escape. This contrivance is calculated to prevent the boiler being burst by suddenly forcing water into it, when it has been allowed by carelessness to boil dry, and become red-hot. A metal plug should always be rivetted into such a boiler. The plug should be made of such a composition of the fusible metal, that it will melt whenever the contents of the boiler attain that degree of heat which produces steam of a dangerous elasticity. Another precaution which should always be taken, is to have two safety-valves fixed in different parts of the boiler; so that if by any accident one of them becomes fixed fast in its seat by rust or other means, the other will be in a state to act, thereby diminishing the chance of an accident to half; and the larger these safety-valves are made, the more certainly they will operate. The mercurial steam-gauge used in most engines is a long curved tube, or inverted siphon, in which the mercury rises by the force of the steam, and indicates the pressure. If this kind of steam-gauge is applied to the high-pressure engine, it requires a very long tube, which is an additional security against the bursting of the boiler, because the mercury will be blown out of the tube, and permit the steam to escape when the pressure is too great.

Before the boiler of a high-pressure engine is set to work, it should be proved effectually, first by drilling small holes through it at different places, to actually measure the thickness of the metal, and ascertain that it is equal throughout; and then it should be proved by injecting water into it, until the pressure lifts the safety-valve, when loaded considerably more than it is intended to be when the engine is set to work; but this proof should not be too severe, because the metal may be weakened, although it is not burst, by the proof; and, in consequence, may afterwards burst with a much less pressure of steam. At the same time, the engineer who undertakes to make these engines, should fully inform himself of the real strength of metal boilers of determinate thicknesses, which could be easily done, without danger, by injecting water into the boilers until they actually burst. We do not know if such experiments have ever been made; and in those boilers which have been burst by the explosion of steam, the pressure at the moment of the accident has not been known.

We have an account of a trial of a small high-pressure engine made in 1804, in Wales, to ascertain its powers to raise water: the cylinder was 8 inches in diameter, and $4\frac{1}{2}$ feet stroke; it worked a pump $18\frac{1}{2}$ inches in diameter, and $4\frac{1}{2}$ feet stroke, which raised water 28 feet high. It worked at the rate of 18 strokes *per* minute, and consumed about 80 lbs. of coals *per* hour: this, when reduced, is about $17\frac{1}{2}$ million pounds raised one foot high for each bushel. Thus, the weight of the column is 3266 lbs. for the area of the pump ($18.5 \times 18.5 = 342.25 \times .7854 =$) 268.8 square inches $\times$ .434 lbs. $=$ 116$\frac{2}{3}$ lbs. the weight for every foot of the column $\times$ 28 feet $=$ 3266.5 lbs. the total weight of the column. The motion of the piston *per* minute is ($4\frac{1}{2} \times 18 =$) 81 feet, or 4860 feet *per* hour $\times$ 3266.5 lbs. $=$ 15,875,160 lbs. raised one foot high *per* hour. The coals consumed in the hour is 80 lbs.; therefore say, as 80 lbs. : 15,875,160 lbs. :: 88 lbs. : 17,462,676 lbs., the number of pounds raised one foot high for each bushel of coals. The area of the piston is ($8 \times 8 = 64 \times .7854 =$) $50\frac{1}{4}$ square inches, and the load $3266.5 \div 50\frac{1}{4} = 65$ lbs. pressure *per* square inch on the surface of the piston.

Manufacture of Steam-Engines. — The great demand for these machines, which has taken place since their value has been so fully understood, has occasioned them to be manufactured in the large way by several engineers, who adopt the same system as is pursued in making of watches and clocks, *viz.* that of having workmen instructed in making the separate parts, and employing machines and tools for every operation which admits of such aid. The first of these manufactories is that of Messrs. Watt and Boulton, at Soho, near Birmingham, sons of the inventor and his associate, who established the manufactory about 1775; and until the expiration of Mr. Watt's patent in 1800, it was the only place where his engines were made. It has continued ever since to furnish the greatest proportion of engines, as well for this country as abroad. There are now other manufacturers who approach the original in the beauty and perfection of the workmanship.

Since the expiration of the patent, there has been a total change in the manner of constructing and putting together every part of the engine, and many advantageous improvements have been made, as far as respects the durability and accurate performance of the machine; though nothing, except the second cylinder of Hornblower and Woolf, has been added to Mr. Watt's engine since he first brought it to a standard, by which its powers are at all increased, with respect to the consumption of fuel, but rather the contrary. At the first establishment of these manufactories, on the expiration of Mr. Watt's patent, many ingenious mechanics attempted to improve the structure of the machine, and the records of the patent office contain more upon this subject, than any other. All kinds of parallel motions have been tried; cylinders have been inverted, placed horizontally, made of long and short proportions; large air-pumps have been used; and for the minor parts, such as valves, and the machinery for actuating them, scarcely two following engines were made alike for many years, until by, the result of a vast deal of invention and experience, those methods which we have described became settled into established forms; but none of them are superior to the original of Mr. Watt's. Respecting parallel motions, and the proportions of the parts, no methods have been found so good as the original engine; and we accordingly find, that all the most established and experienced manufacturers make engines which are not altered in any great feature from Mr. Watt's original engine, with a beam and parallel motion acting on a simple crank; and they give them all the advantages which can be derived from superior workmanship, and improved methods of putting the parts together, which experience has pointed out.

Messrs. Fenton, Murray, and Wood, of Leeds, Yorkshire, are the manufacturers of the most established reputation after Messrs. Watt and Boulton. The engines they send out cannot be excelled in beauty and perfection of workmanship, and they perform as well as any others. Their factory at Leeds is very extensive, and provided with every convenience for making all the parts of the engine in the best manner, and with the least labour. They have three

fteam-engines in the works, one for boring cylinders, and turning large lathes; a fecond for turning fmall lathes, grinding, drilling the centres of wheels, tapping fcrews, &c., and for blowing the furnaces of the foundery; and a third engine for working a great forge hammer, by which the heavy wrought iron work is forged. The boring machines for cylinders, of which they have three in number, are very capital, as by an ingenious movement, invented by Mr. Murray, for drawing the borer through the cylinder, it is made to advance regularly from one end to the other, without any interruption. Thefe machines are worked by a feparate fteam-engine, which is never ftopped during the operation of boring a cylinder through, as it is found to make a fenfible mark or ring if the motion is ftopped. The beft means are alfo taken to prevent the cylinder from changing its figure by its weight, or by the preffure of the parts which hold it in its pofition. The whole of the factory is lighted by gas lights in winter time. The boilers are manufactured by the aid of feveral machines to cut out the plate, pierce the holes, and bend the joints. Before any of the fmaller engines are fent away, all the parts are put together in a building on purpofe, where there are boilers fixed and they are actually tried, to infure that every part is perfect: they are then taken to pieces, with marks and directions for putting them together, and packed up for carriage, which is very eafy, as there is a canal at the gates, which has communication by water to every part of England. For fuch engines as are too large to be put to work at the factory, workmen are fent out with them, to affift and direct in fetting them to work.

In London, Mr. Maudflay has made many very excellent fteam-engines upon the plan reprefented in our fketch; but his beft engine, which is in the faw-mill at Woolwich, is with a beam upon Mr. Watt's plan. He has lately made a large engine for a fteam-boat invented by Mr. Brunel, which has two cylinders acting alternately upon different cranks, formed upon the fame axis at right angles to each other, fo that the motion is continued without a fly-wheel: one boiler is placed between the two cylinders, and one air-pump and condenfer exhaufts them both. By this means a powerful engine is contained in a fmall fpace, and is not heavy to load the boat.

Some engineers of Manchefter make very good fteam-engines, chiefly for the great cotton-mills. At moft of the iron furnaces in the country, fteam-engines are now made, and fome of them produce very capital engines, as at Butterly in Derbyfhire, Low Moor in Yorkfhire, and others. Their workfhops are in general managed by engineers who have been educated at Soho, or at Leeds. Mr. Woolf's engines are made in London by Mr. Edwards, and by himfelf in Cornwall.

Rotative Steam-Engine. — The reciprocating motion of a fteam-engine has always been confidered as a great defect; for though all irregularity of motion can be obviated by connecting it with a fly-wheel, yet a great mafs of matter muft always be kept in a conftant fucceffion of changes from reft to motion; and the irregularities which this would produce, can only be governed by putting a great mafs of matter in the fly-wheel, and caufing it to move with a rapid motion, fo that its momentum or vis inertiæ fhall be vaftly greater than that of all the reciprocating parts together. With a view of obviating this objection, and of obtaining the action of fteam by more fimple machinery than a cylinder and pifton, many attempts have been made to produce a circular motion at once by the fteam. It has been made to blow on the vanes of a wheel of various forms. But the rarity of fteam is fuch, that even if none is condenfed by the cold of the vanes, the impulfe is exceedingly feeble, and the expence of fteam, fo as to produce any ferviceable impulfe, is enormous. Mr. Watt, among his firft fpeculations on fteam-engines, made fome attempts of this kind; but he has not given fuch a defcription of the valves for this purpofe, as to enable an engineer to conftruct one of them. From any guefs that we can form, we think the machine very imperfect. One of Mr. Watt's firft trials was uncommonly ingenious; it confifted of a drum, turning air-tight within another, with cavities fo difpofed, that there was a conftant and great preffure urging it in one direction. But no packing of the common kind could preferve it air-tight with fufficient freedom of motion. He fucceeded by immerfing it in mercury, or in an amalgam which remained fluid in the heat of boiling water; but the continual action of the heat and fteam, together with the friction, foon oxydated the fluid, and rendered it ufelefs. He then tried Parent's or Dr. Barker's mill, inclofing the arms in a metal drum, which was immerfed in cold water. The fteam rufhed rapidly along the pipe which was the axis, and it was hoped that a great re-action would have been exerted at the ends of the arms; but it was almoft nothing. The reafon feems to be, that the greateft part of the fteam was condenfed in the cold arms. It was then tried in a drum kept boiling hot; but the impulfe was very fmall, in comparifon with the expence of fteam: this muft be the cafe.

Mr. Watt has defcribed in his fpecification of 1782, lodged at the patent office, fome more perfect contrivances for producing a circular motion by the immediate action of the fteam. One of thefe produces alternate motion upon a centre, and is analogous to the double engine; another produces a continued motion. See his firft fpecification of 1769.

We do not find that Mr. Watt has ever erected a continuous circular engine: he has doubtlefs found all his attempts inferior to the reciprocating engine with a fly. A very crude fcheme of this kind may be feen in the Tranfactions of the Royal Society of Dublin, 1787.

Mr. Cartwright, in a patent of 1797, propofes fome improvement of Mr. Watt's rotative engine, but it was never brought into ufe. Mr. Jonathan Hornblower had a patent in 1798 for a rotative engine, which is the moft ingenious of all the fpeculations on this fubject, but too complicated to be carried into execution; and in 1805 he had another patent, for a machine which is quite different from the former, and is ingenious, but ftill lefs likely than the firft to anfwer the intended purpofe.

Mr. Samuel Clegg has made a rotative engine, the pifton of which makes a complete revolution in a channel at a diftance from the centre of motion. We have feen this engine at work, which acted in a very regular manner, but we think the friction muft be greater than that of a common engine, although it gets rid of the reciprocation. Mr. Clegg had a patent in 1809 for his invention.

Mr. Turner has lately obtained a patent for a rotatory fteam-engine, the principle of which is the fame as Mr. Clegg's, but each of them has its peculiar advantages in the manner of fitting up, and in the arrangements of its parts. Mr. Turner's is packed in all the moving parts with metallic packings inftead of hemp, and we have been informed that his engines operate very well, and without any fly-wheel. Mr. Clegg's engine only requires a fmall fly at one part of its movement. We think, that if ever rotative engines are brought to perfection, it will be by fomething of the nature of thefe two engines, which are the moft practicable, and promife greater probability of fuccefs than any before invented.

For the application to fteam-boats, and to the purpofe of drawing carriages, or locomotive engines, as they are now called, rotative engines would be fo advantageous, that they

would be very useful, even though they should consume rather more fuel than reciprocating engines of the same power, provided they were certain in their action.

Cement for making Joints in Steam-Engines. — In joining the flanches of iron cylinders, and other parts of hydraulic and steam-engines, a strong and durable cement is required. The following are receipts for cements proper for such purposes. Mix boiled linseed oil, litharge, red and white lead, together to a proper consistence: this cement is to be applied on each side of a piece of flannel, previously shaped to fit the joint, and then interposed between the flanches, before they are brought home to their place by the screws or other fastenings employed, which will make a close and durable joint. The quantities of the ingredients may be varied without inconvenience, only taking care not to make the mass too thin with the oil. It is difficult, in some cases, to make a good fitting of large pieces of iron work at once, and this renders it necessary sometimes to join and separate the pieces repeatedly, before a proper adjustment is obtained. When this is expected, the white lead ought to predominate in the mixture, as it dries much slower than the red. A workman knowing this fact, can exercise his own discretion in regulating the quantities; but it is safest to have too much rather than too little white lead, as the durability of the cement is no way injured thereby, only a longer time is required for it to dry and harden. When the fitting will not admit of so thick a substance as flannel being interposed, linen may be substituted, or even paper or thin pasteboard, the only reason for employing any thing of the kind being the convenience of handling. This cement answers well also for joining broken stones, however large. Cisterns built of square stones put together with this cement, will never leak or want any repairs: in this case the stones need not be entirely bedded in it, for an inch or even less of the edges that are to lie next the water need only be so treated, and the rest of the joints may be filled with good lime.

Another cement, which is preferable to the former for withstanding the action of steam, is compounded as follows: Take two ounces of sal ammoniac, one ounce of flour of sulphur, and 16 ounces of cast-iron filings or borings: mix all well together by rubbing them in a mortar, and keep the powder dry. When the cement is wanted for use, take one part of the above powder, and 20 parts of clean iron borings, or filings, and blend them intimately by grinding them in a mortar: wet the compound with water, and when brought to a convenient consistence, apply it to the joints with a wooden or blunt iron spatula. — By considering the affinities of these ingredients, those who are at all acquainted with chemistry, will be at no loss to comprehend, that a degree of action and re-action takes place among the ingredients, and between them and the iron surfaces, which at last causes the whole to unite as one mass: in fact, after a time, the mixture and the surfaces of the flanches become a species of pyrites, holding a very large portion of iron, all the parts of which cohere strongly together. Another cement of the same kind is made by mixing together two parts of flour of sulphur, and one part of sal ammoniac, and making them into a stiff paste with a little water. When the cement is wanted for use, dissolve a portion of the above paste in urine, or in water rendered slightly acidulous; and to this solution add a quantity of turnings or borings sifted, to get rid of the grosser particles. This mixture, spread upon or between the flanches of iron pipes, or put into the interstices of other parts of iron work, will in a little time become as hard as stone.

Mr. Murray's Rule for the Weight of Fly-Wheels to Steam-Engines.—Mr. Buchanan, in his valuable treatise on propelling vessels, printed at Glasgow in 1816, gives the following rule, as the result of Mr. Murray's long experience in building engines.

Rule.—Multiply the number of horse-power of the engine by 2000, and divide it by the square of the intended velocity of the circumference of the fly-wheel in feet *per* second, the quotient will be the weight of the fly-wheel in hundred weights.

Example.—To find the weight of a fly-wheel proper for an engine of 20 horses' power, supposing the fly-wheel to be 18 feet in diameter, and to make 22 revolutions *per* second: wheel 18 feet diameter 56 feet circumference $\times$ 22 revolutions *per* minute $=$ 1232 feet motion *per* minute $\div$ 60 $=$ $20\frac{1}{2}$ feet motion *per* second for the motion of the circumference of the fly wheel. Then $20\frac{1}{2}$ feet *per* minute squared $= 420\frac{1}{4}$, and 20 horses' power $\times$ 2000 $= 40000 \div 420\frac{1}{4}$ $=$ 90.4 cwt. of the wheel required.

Smoke-Burning Furnaces for Steam-Engines.—The great quantity of smoke which is thrown out by the furnaces of steam-engines, becomes a great annoyance in a town such as Manchester or Birmingham, where there are many engines together. To avoid this, as well as from an idea of obtaining a greater effect from the combustion of the smoke, many inventors have been induced to contrive furnaces which shall not produce any smoke. The black smoke which is usually discharged at the top of the chimney, is, in fact, so much good fuel, which only wanted a sufficient heat, and the contact of fresh air, to inflame it under the boiler. It is a fact well known, that the flame which is often seen issuing from the top of the chimnies of founderies, furnaces, &c. has no existence except at the top of the chimney; for while it is ascending the flue, it is only dense, black smoke, consisting of the azote of the atmospheric air which has passed through the fire, of hydrogen gas, coal-tar, and carbonaceous matter; and this smoke is of such a high temperature, that it only requires oxygen to make it inflame instantaneously: this it obtains from the atmospheric air, into which it descends on issuing from the top of the chimney, and then presents such appearances, as would make a hasty observer adopt the opinion that the flame had ascended, in the state of flame, from the fuel in the furnace, through the whole height of the flue, up to the top of the chimney; but this is by no means the case, and a consideration of this simple fact will convince any person, that it is not an inconsiderable proportion of the fuel that is thus wasted. Nor is this the only loss sustained; a quantity of heat is required, not merely to render such a portion of the fuel volatile, but to give it a temperature sufficient to produce the spontaneous inflammation at the top of the chimney, of which we have taken notice. This must be furnished at the expence of an extra and unnecessary quantity of fuel.

The first of the smoke-burning furnaces was Mr. Watt's patent of 1785. His method consists in causing the smoke, or flame, of the fresh fuel, while passing from the fire to the flue or chimney, to pass, together with a current of fresh air, through or among fuel which has already ceased to smoke, or which is converted into coke, charcoal, or cinders, and which is intensely hot; by which means the smoke, and grosser parts of the flame, by coming in close contact with the intensely hot fuel, and by being mixed with the current of fresh or unburnt air, will be consumed or converted into heat, or into pure flame, free from smoke. This invention is put in practice, first, by stopping up every avenue or passage to the chimney or flues, except such as are left in the interstices of that part of the fuel which is ignited; secondly, by placing the fresh fuel above, or nearer to the external air, than that which is burning, and already converted into coke or charcoal; thirdly, by constructing the fire-place in such

manner, that the fresh atmospheric air which animates the fire, and the smoke or flame which rises from the fresh fuel at the first application of the heat, must pass downwards, or laterally, so as to pass through the whole mass of burning fuel, and issue from the interstices of the burning fuel at the most remote part, or internal end of the fire-place, to escape into the flues or chimney. In some cases, after the flame has past through the burning fuel, it is made to pass up a very hot funnel, flue, or oven, before it comes to the bottom of the boiler, by which means the smoke is still more effectually consumed.

This invention of Mr. Watt's has been very extensively practised; but another plan, by Mr. Roberton of Glasgow, has since been found preferable: it is nearly on the same principle as Mr. Watt's. The opening through which the fuel is introduced into the furnace is shaped like a hopper, and is made of cast-iron, built into the brick-work of the furnace. From the mouth, or entrance of the hopper, it inclines downward to the place where the fire rests on the bottom grate.

The coals in the mouth-piece, or hopper, answer the purpose of a fire-door; and the principal point to be attended to in the management of this furnace is, that the hopper shall be kept full of coal, either wholly or in part with small coal, to prevent as much as possible the air entering by that passage. The coals which are in the lowest end of the hopper are brought to a state of ignition by the heat of the fire upon the bars, before they are forced upon the bars to be burned.

Beneath the lower part of the hopper the furnace is provided with front bars, which serve to admit air among the fuel which lies upon the grate, and offer a ready mode of forcing the ignited fuel, which has just issued from the lower part of the hopper, back upon the fire-grate, where it is completely consumed, and by thus forcing it back, a space is made, into which fresh fuel falls from the lower part of the hopper; but all the smoke which rises from this fresh fuel must pass through the burning fuel, which lies upon the farther part of the grate, and is thus consumed. By this arrangement, the fuel is brought into a state of ignition before it reaches the farther side of the bottom grate, where it is stopped by a rising breast of brick-work; therefore, any smoke which is liberated from the raw coals in the mouth-piece, must pass over these burning coals before it can reach the flue of the chimney; but this, though it would cause a large quantity of the smoke to be burnt, would not completely prevent the escape and ascent of smoke up the chimney; for it is not sufficient that the smoke should be exposed to a heat sufficient to ignite it before it escapes; as, unless a quantity of fresh air, able to furnish a sufficiency of oxygen for the combustion of the smoke, can be brought at the same time in contact with it, it will still escape in an undecomposed state.

The principal merit of Mr. Roberton's invention consists in a judicious admission of fresh air, in such a manner that it can reach the smoke without previously passing through the fire, and parting with its oxygen in its passage, and that it shall be in such quantity, as merely to cause the smoke to burn, and not to cool the bottom of the boiler. Beneath the upper side of the mouth-piece, or hopper, which incloses the fresh fuel, and at the distance of about three-fourths of an inch from it, (this space being a little more or less, according to the size of the furnace,) is placed a cast-iron plate, which is above the hopper containing the fuel; and in the space between it and the top of the hopper is an open space for the admission of a thin stream of air, which, rushing down through the opening, comes first in contact with that part of the fire which is giving out the greatest part of the smoke; *viz.* the fuel that has been last introduced from the lower end of the hopper upon the grate-bars, mixes with the smoke before it passes over the burning fuel upon the interior part of the grate-bars, where it is in in a high state of combustion: this enables the smoke to inflame completely. The quantity of air thus admitted to pass over the upper surface of the fuel newly introduced, is a matter of importance to the complete action of the contrivance. The opening for air is regulated by a very simple contrivance. The plate which forms the upper side of the opening for the passage of the air, rests at each end on a stud, or pin, projecting from the cheeks of the mouth-piece, or it is furnished at each end with a pivot, which works in the cheeks. These pins, or pivots, being placed about half-way between the outside and inside of the mouth-piece, or hopper, by elevating or depressing the outer edge of the plate, the opening for the admission of air between the lower end of the hopper and the lower edge of this plate can be diminished or enlarged. When that degree of opening which produces the best effects is obtained, which is easily known by experiment, the plate is kept in its place by means of a piece of iron introduced above it, and answering the purpose of a wedge. These furnaces have been adopted by many manufacturers at Leeds, Manchester, and in London, where many works have been indicted as a nuisance for not having adopted the improvement; the magistrates arguing, that though the welfare of the place required that such inconveniencies should be submitted to while no possible remedy for them was known, the health and comfort of the inhabitants equally demand, now that evil can be done away, that smoking furnaces should not be permitted in the place. On this account, Mr. Roberton's furnaces have been very much adopted; but we have seldom seen them in such order as to make any diminution in the smoke, which they will do completely, if the regulation of the quantity of air is properly made.

A recent invention by Mr. John Cutler in 1815, is found to burn the smoke most perfectly in common fire-grates, such as are used for warming apartments; and we have seen an experiment of this plan upon a small engine boiler, which seemed to promise great success in applying it on a larger scale; but such trials have not yet been made, nor the best form of the apparatus settled.

Mr. Cutler's invention consists in applying beneath the place in which the fire is to burn, a chamber or magazine, which is made as close as can be on all sides, except the top, and is of sufficient capacity to contain within it a magazine of fuel, sufficient to supply the combustion for a whole day, or other required space of time. The fire is made upon the top of the mass of fuel which is contained in the magazine, and there are no grate-bars upon which the fire is to lay; but instead, the bars are placed at the side, in a sloping direction, so as to inclose the fire in a grating, which will admit sufficient air sideways to supply the combustion. The bottom of the magazine is made moveable up and down in the chamber; and by means of a rack and pinion, a screw, or some other mechanical power, the whole weight of coals contained in the chamber can be raised up, and a portion will rise up into the grated part, where air is supplied to it, so that it can burn; for the principle of this invention is to make the magazine-chamber beneath so close as to exclude the air from it, so that the fire cannot burn the fuel contained in it, and to provide that part of the fire-place which is immediately above the top of the chamber with a plentiful supply of air to burn the fuel. By means of the machinery, any

quantity of fuel can be raifed up out of the magazine-chamber to fupply the deficiency occafioned by the combuftion.

The manner in which it burns the fmoke, is by obliging it to pafs through the burning fuel which lies upon the top of the mafs of coal contained in the magazine, becaufe this burning fuel communicates fufficient heat downwards to make the fmoke rife from the fuel, and this fmoke muft pafs through the fire above it; but before the fuel comes to be actually burned, the fmoke is fo far extracted, that the coal is in the ftate of coke.

The machinery by which the bottom plate of the magazine and the fuel contained in it is raifed up, is fimply an axle, with chains winding upon it; at leaft that is the contrivance which Mr. Cutler ufed in the fmall ftoves for warming apartments; but what method will be found beft on a large fcale, for its application to fteam-engines, remains yet to be determined. We fhall give a more minute defcription of this valuable invention under the article STOVE.

The Application of the Steam-Engine to propel Boats or Ships.—This is one of the moft valuable applications of the power of fteam, next to that of draining mines; and though propofed at a very early period, has been but lately brought into ufe.

Captain Savery, in 1702, mentions the application of his engine to a fhip, but gives no account of the manner of carrying it into execution; probably he only intended it for pumping out leakage-water.

Mr. Jonathan Hull's patent of 1736, for carrying veffels or fhips into or out of any harbour, port, or river, againft wind or tide, or in a calm, is the firft idea of applying the fteam-engine to the purpofe of propelling veffels. The engine of Newcomen was made to actuate a wheel placed in a frame projecting from the head of the boat, and the oars or paddles of the wheel were to ftrike in the water, and advance the boat or veffel containing the engine, which would draw after it the fhip or veffel that was to be rowed into or out of the harbour. We have no account of any actual trials made by Mr. Hull; but befides his patent, we have a fmall pamphlet, printed in 1737, with an engraving.

The account which Mr. Buchanan gives of the introduction of fteam-boats in his treatife on propelling veffels, is, that Mr. Miller of Dalfwinfon, who made many models and experiments with a view to the improvement of naval architecture, appears to have made the firft attempt at working a veffel with fteam. The veffel was double, with the paddle-wheels in the middle: the experiment, however, did not fucceed to his fatisfaction.

About the year 1795, lord Stanhope conftructed a veffel, which was tried in Greenland dock: the paddles were made in the imitation of the feet of a duck, and were placed under the quarters of the veffel, but the mechanifm did not anfwer his lordfhip's expectation.

In the year 1801, Mr. Symington tried a veffel propelled by fteam on the Forth and Clyde Inland Navigation, but it was laid afide, on account of the injury which it threatened to the banks of the canal, by the furge of water which it made. It does not appear that he tried this veffel on any river.

Mr. Symington's fteam-boat is flightly defcribed in the Journals of the Royal Inftitution for 1803, from which it appears, that the method employed by him for making the connection between the pifton and the water or rowing wheel, was by placing the cylinder nearly in a horizontal pofition. This is attended with feveral advantages: the neceffity for a beam is avoided, which has ever been a troublefome and expenfive part of the common engine. The pifton is fupported in its pofition by friction-wheels, and communicates, by means of a rod, with a crank connected with a wheel, which gives a motion to the rowing-wheel fomewhat flower than its own; the water-wheel ferving at the fame time as an addition to the fly. The fteam-engine differs but little in its action from that improved by Mr. Watt; there is, however, an apparatus for opening and fhutting the cock at pleafure, in order to reverfe the motion of the wheels, and put the boat back whenever it may be neceffary. The water-wheel is fituated near the ftern, and in the middle of the breadth of the boat, fo that it becomes neceffary to have two rudders, connected together by rods, which are moved by a winch near the head of the boat: by this means the perfon who attends the engine is able to fteer alfo.

Another part of Mr. Symington's invention confifted in the application of ftampers at the head of the boat, for the purpofe of breaking the ice on canals: thefe were to be raifed in fucceffion by means of levers, the ends of which were depreffed by the pins of wheels, turned by an axis communicating with the water-wheel. Mr. Symington ftated, in a calculation he made, that a boat doing the work of twelve horfes, could be built for eight or nine hundred pounds; and he had afcertained by experiment, that it would travel at the rate of two miles and a half *per* hour. This is a very flow motion, compared with the prefent fteam-boats, as we fhall fee.

In 1807, Mr. Fulton of New York introduced fteam-boats into America, which were the firft that fucceeded in a large way, fo as to become profitable: they had before this been ufed in America, and were began there by Mr. Symington. In 1812, a large boat was fet to work on the Clyde, in Scotland; and fince that time, great numbers have been made both in Scotland and in different parts of England.

There are feveral different methods of applying the force of machinery to row boats: the moft obvious is by means of oars, fimilar to thofe with which a boatman rows; but this action is very difficult to imitate by machinery, and has never been brought into practice. Several ingenious fchemes may be found in the Machines Approvées par l'Academie.

The next is by means of paddle-wheels, which are fimilar to an underfhot water-wheel; and when turned rapidly round by the engine, the floats dip into the water, and row the boat along. This plan was firft put in practice by the ingenious captain Savery, in 1702; but to be turned by men working at a capftan inftead of a fteam-engine, is now adopted in all the real working fteam-boats which have been made. Two wheels are ufually placed at the fides of the boat, at about one-third of the length from the head. Attempts have been made to place one wheel in the middle of the boat, but they have not fucceeded fo well as the others.

Another method is by forcing a ftream of water out at the ftern of a boat by a large pump, which at the fame time draws the water in at the head of the boat. This was fuggefted by Dr. Franklin, after M. Bernoulli, and was very effectually tried by the late Mr. James Linaker, mafter millwright of the dock-yard at Portfmouth, but found inferior to the paddle-wheels. It has been alfo propofed to force out air under the ftern of the veffel by a pump, but we do not think it likely to fucceed.

A fifth method is by a fcrew applied at the ftern of the veffel, and turned round by the engine.

Laftly, various forms of oars have been applied at the ftern of the veffel to move from fide to fide, and impel the veffel on the fame principle, as what feamen call fkulling a boat, by an oar at the ftern.

As none of thefe fchemes, except the paddle-wheels at the outfides of the boat, have been brought to any practical utility, we fhall not enter into any further particulars, but defcribe one of the beft of thefe veffels, fuch as is employed on the Clyde at Glafgow, where fteam-boats have been brought to the greateft perfection.

All thefe veffels are upon one general plan, *viz.* that of having paddle-wheels, fimilar to underfhot water-mill wheels, on each fide of the boat, which are put in motion by the fteam-engine. In fome of thefe wheels the paddles are placed parallel to the axis of the wheel, in others they are placed obliquely, and in others again they are curved; and it is not yet afcertained which is the beft form; for although fome boats are found to move with a much greater velocity than others, it is difficult, where fo many caufes are combined in the operation, to afcertain which one fingly produces the advantageous effect. Experiments are yet wanting to afcertain the beft number for the paddles on the wheel, and with what velocity they fhould move. It would doubtlefs be of advantage to have the means of changing the velocity of the paddle-wheels, according to the circumftances of the current of the water in which the boat moves; becaufe when the boat is moving with the current, the paddle ftrikes againft the water in a contrary direction to its motion, and therefore has the greateft force to urge the boat forwards, at the fame time that the boat is moving in the direction of the current, and therefore moves more eafily. On the other hand, fuppofe the boat moving againft the current, the paddles muft row the water in the direction of the current, fo that fuppofing they move only with the fame velocity, they muft have much lefs force to advance the boat, at the fame time that the boat, having to oppofe the current, requires a greater force to propel it. One of the fteam-boats on the Clyde has eight paddles to each wheel, but it is probable feven would be more effective; becaufe it is evident, that if too many paddles are ufed, the water will be fo much broken, that it cannot afford that refiftance to the motion of the paddle which alone caufes the boat to advance. For an extreme cafe, fuppofe fo great a number of paddles that they would nearly touch, the wheel would then refemble a folid cylinder, and have no effect to propel the veffel. The velocity with which the paddle ftrikes the water muft be confiderable, to obtain a great refiftance from the water; but the ftroke muft not be too frequently repeated, or the water which the paddle removes will not have time to return to its level before the fucceeding paddle makes its ftroke.

The fteam-engine is placed near the middle of the veffel, and the fmoke is carried up in a large plate iron tube, which ferves the purpofe of a maft, to hoift a fail when the wind favours. The greateft number of boats at prefent in ufe are fitted up for paffage-boats, as that is the moft profitable employment: they have two cabins, one before the engine, which is fmaller, and confidered inferior, while the fecond, or large cabin, abaft the engine, is more elegantly fitted up. *Plate* VIII. *Steam-Engine, fig.* 1. is an elevation of the whole veffel, as fhe appears in the water, and *fig.* 2. a plan with the deck removed, to fhew the arrangement of the apartments, and to explain the fteam-engine and machinery by which the veffel is propelled.

That part of the boat which is beneath water, is built like an ordinary boat, which draws but little water, and fhe is fo formed at the ftern-parts as to caufe her to fteer readily. The head muft be built more bold or rounding for thofe boats which are intended for the fea, than thofe for rivers, which are generally made very fharp at the head, fo as to divide and move more freely through the water. The rudder and tiller are conftructed the fame as other boats. The width of the veffel above water is confiderably increafed, by the addition of galleries or gangways, X, X, which are fixed projecting from her fides and gunwale: they are compofed of a thin planking, and are fupported by knees and ftanchions, fo as to form a gangway to walk round, and at the fame time a defence to the paddle-wheels B, B, which are placed clofe to the fides of the veffel in the width of the gangways. Thefe wheels are put in motion by the fteam-engine, and by their action againft the water propel the boat forward. The paddle-wheels are conftructed nearly in the fame manner as underfhot water-wheels, except that the floats or paddles are placed inclined to the axis, inftead of being perpendicular to the plane of the rim of the wheel. The upper parts of the wheels are inclofed in femi-circular cafes of thin boarding Y (*fig.* 1.), to prevent the action of the wind upon their floats, which, without this precaution, would materially impede their motion, becaufe the floats at the upper part of the wheels move in a contrary direction to thofe at the lower part, where they dip into the water.

The fteam-engine which gives motion to the wheels, is fituated in the middle of the boat; but it muft be placed low, and, if poffible, beneath the water-line, fo as to act in part as ballaft to the boat, which will otherwife require a greater quantity of ballaft than ufual to counteract the weight of the engine. It is a great advantage to thefe boats to be light, and draw little water; thefe engines muft therefore be made as light and compact as is poffible, that none of the parts fhall break. The principal parts which require ftrength fhould be made of good wrought iron, in preference to caft iron, which is ufed for other engines; for inftance, the beam and connecting rods, and alfo the cranks and fhaft for the fly-wheel, as well as thofe for the paddle-wheels. The wheels themfelves are made of thick iron plate or wood; the boiler A (*fig.* 2.), in which the fteam is produced, is made of ftrong wrought-iron plates, and as large as the fpace which can be allowed for it will admit, that it may produce a regular fupply of fteam to the engine: it is placed fometimes acrofs the veffel, and fometimes in the direction of its length, as fhewn in the figure; and the fire-place is an iron tube contained withinfide: *l* is the fire-door: the fmoke, after paffing through two or three turns of the tube in the boiler, paffes off through the chimney C, which is an iron tube, erected perpendicularly in the centre of the veffel, to a confiderable height, as fhewn in the elevation, and is ftayed, in the fame manner as a maft, by two ropes, or fometimes by iron chains from its top, going fore and aft, with a purchafe to each to draw them always tight. There is a fafety-valve at *d*, by which the fteam efcapes into the chimney when it is produced in too great a quantity, and becomes too ftrong, or when the engine is not in motion: *e* is the fteam-pipe, which conveys the fteam from the boiler to the fteam-box *f*, which contains the four valves for diftributing the fteam into the cylinder G, alternately above and below the pifton, fo as to give motion to the engine. Thefe valves are made to work on the plan of Mr. Murray's patent, with the fpindle of one through the other. The top of the pifton-rod is jointed to the middle of a crofs-rod, from the ends of which the two iron rods defcend, one on each fide of the cylinder, and are jointed to the beam, G P, which is made double, or compofed of two levers, joined together in the manner of a frame, fo that the caft-iron condenfing ciftern of the engine is contained between the two, as they work up and down: the beam-centre, or axis of motion, is fupported by two bearings fcrewed up to the bottom of this ciftern, fo that the beams lie clofe to each fide of the ciftern: the cylinder is fcrewed down upon one end of the condenfing ciftern, and the bearings for the axis of the crank, R, are fupported on the other end. The beams, G P, are united together at the extremity moft remote from the cylinder by a crofs rod, on

the middle of which the connecting rod is jointed, which rises upwards to the crank R, on the shaft or axis of the fly-wheel M: this crank-axis is supported in bearings close on each side of the crank, which are framed to the condensing cistern, and also two others at the extremities of the axis, which are placed on the gunwale of the boat, so that the shaft extends completely across the vessel, passing through the boiler A, in a tube which extends across it, as shewn by dotted lines at *a*. On each end of the crank-shaft two cog-wheels are fixed, engaging in the teeth of two other wheels, O, O, fixed upon the shafts of the paddle-wheels B, B. These last-mentioned shafts are each supported in two bearings, one on the outside beam of the gangways or platforms, and the other on the gunwale of the vessel: the cog-wheels, O, O, are fixed on the extreme ends of the shafts within the vessel, and they are one-third or one-fourth larger than the wheels on the axis of the crank, so that the paddles do not turn so fast as the fly-wheel of the engine.

It is needless to enter into a description of the action of the steam-engine: the construction of the valves is the same as described in a former part of this article (*Plate* VII. *fig.* 5.), and the engine acts the same as Mr. Watt's double-acting engines; but it is necessarily modified, to suit its particular situation, which occasions some defects. The cylinder must be made very short, to come into the height of the boat; and the connecting rod is so short, that the obliquity of its action on the crank is very great. The air-pump, H, is worked by a cross-rod, which moves up and down with the beams, being connected to them by perpendicular rods. The requisite movement is communicated to the valves of the engine by the rod *i p*, one end of which has a circular hoop, that embraces an excentric wheel *p*, fixed on the axis of the fly-wheel; so that in turning round, it pushes the rod *i p* backwards and forwards, in the manner of a crank, and thereby alternately opens and shuts the valves at the proper instant to produce the motion. There is a throttle-valve placed in the steam-pipe at *e*, for regulating the velocity, or stopping the engine, when required.

The arrangement of the apartments in a steam-vessel may be varied according to the purpose for which she is to be employed. In the drawing, we have given the arrangement which appears best adapted for the convenience of passengers, in a vessel for quick travelling (See the plan, *fig.* 2) The after or grand cabin, marked 1 in the figure, is generally fitted up and furnished in an elegant style, for the use of the best company, who also occupy the deck and gangways abaft the chimney. The entry to the grand cabin is at the stern of the vessel. The grand cabin is generally situated in the after-part, on account of there being the most room in that part, the engine being always placed considerably nearer the head of the vessel than the stern: 3 is a small room for the use of the passengers, and has a door coming out on the gangways. The entry to the engine-house is by steps from the gangway on the opposite side; and the same entry serves for a small room 4, in which the steward keeps his stores. The coals for working the engine are stowed beneath the floors of the cabins, and the engine-man draws them out with a long hook as he wants them. The fo ward-cabin, 5, is for passengers who pay less than the others: it has a large counter or chest in the middle, which will contain all the luggage, and serves also as a table for those who sit round it. These passengers have the use of the deck forwards of the chimney; but the gangways at that part are almost entirely occupied by a large water-cask on each side, the cable, spare sails, or whatever the vessel may require. The rigging of the boat is evident from *fig.* 1: she carries two large lugger-sails, one fore and the other aft; but as these are only intended to be used in fine weather, with a fair and light wind, the masts and cordage may be as light as is convenient. A pair of halliards should be provided to the chimney, to hoist occasionally a large light lugger-sail; and if the chimney is not sufficiently strong, a pair of extra stays may be set up to strengthen it. The chimney is generally made to lower down, for the convenience of passing bridges, when the vessel navigates a river.

The paddle-wheels of one of the boats on the Clyde, which, Mr. Buchanan says, is considered as a standard, are 8 feet 10 inches diameter, and 4 feet wide, and are calculated, when the engine makes 45 strokes *per* minute, to move at the circumference, or strike the water at the rate of 13 miles *per* hour. She is about 80 tons burden, and is 69 feet from stem to stern, and 15 feet 2 inches wide in the beam. The engine is of 14 horses' power, and she goes at an average six miles *per* hour in still water: therefore, if there is a current, she will go as much faster or slower than six miles *per* hour as the velocity of the current. The motion of the paddles is rather more than twice that of the boat.

Steam-boats have been built with much more powerful engines, even 20, 25, and 30-horse power; but the increase of the velocity has not been in proportion to the increase of the power of the steam-engines. This will not be surprising, when it is considered that the resistance to which a boat is subject, increases not in an arithmetical proportion, (as 1, 2, 3, 4, 5, &c.) but in proportion to the squares of velocity (as 1. 2. 4. 8. 16. 32.) In other words, to make the same vessel move with ten times a given velocity, it requires one hundred times the power; and it is farther to be considered, that one or more powerful engines above mentioned are heavier, and require a greater floating body to support them, which of course increases the resistance. On railways, an increase of velocity requires only an arithmetical increase of power; and to draw a carriage on a railway with ten times a given velocity, would require only ten times the given power.

Steam-boats require a greater power of steerage than any other vessel of their size, as those hitherto constructed are less easily turned than vessels impelled by sails only. The tendency of the wheels acting so near the centre line of the vessel, is to propel her straight forward; whereas in turning a sailing vessel to the wind, the sails aid her in coming about; and even common oars act so far out from the side of the vessel, that they have much more power to bring her round than the wheels of a steam-boat can possibly have.

A most important point is to have a good steam-engine. All the engines hitherto used in Scotland have been made on Mr. Watt's principle; but those in America have been high-pressure engines, which being more simple, and less expensive, some have been constructed in England. But one of them having exploded in an American boat, the proprietors of some of the English boats have changed their engines for others on Mr. Watt's principle, to avoid similar accidents. We think it quite unjustifiable in any engineer to advise the construction of steam-boats with high-pressure engines, at least for passage-boats, in which so many persons are always assembled together, and so near to the engine, that they would be all destroyed in the event of the boiler bursting.

Those engines which work with a bell-crank, or a double beam, below the cylinder, and on each side the cistern, instead of a beam working above, are found to strain the vessels: those having the beam above, work much more

ſteadily. The engines that Meſſrs. Boulton and Watt have hitherto conſtructed have had beams: other engines have had cylinders horizontally. Mr. Brunel's engine, of which we have before ſpoken, has two cylinders acting alternately, ſo as to require no fly-wheel; but many engines, on the common conſtruction, have been made without fly-wheels, by having the paddle-wheels ſufficiently heavy to anſwer the purpoſe.

With regard to fuel, it is obviouſly much more difficult to have every thing kept in proper order in a boat, where the engines are much confined, and the cylinder is made to work with very ſhort ſtrokes, by which the action on the crank is ſo oblique, and changes its direction ſo frequently, that the greater part of the power is loſt. The quantity of fuel conſtantly uſed in ſteam-boats has been much greater than the uſual allowance for Meſſrs. Boulton, Watt, and Co.'s ſteam-engines. For one of 14-horſe power, they allow 1 cwt. 1 qr. 20 lbs. *per* hour of good Newcaſtle coal; but Glaſgow coal is much weaker. One of the boats, with an engine of 33 horſe power, requires 3 tons 12 cwt. from Glaſgow to Greenock (fully 29 miles), and back to Glaſgow. One of 15-horſe power, and another of 8-horſe power, take each the ſame quantity, *viz.* from Glaſgow to Greenock (26 miles), and back to Glaſgow, 1 ton 1 cwt. For farther particulars on ſteam-boats, ſee Roberton's Eſſay on Propelling Veſſels, 8vo. 1816.

The Application of Steam-Engines to driving of Carriages.— Theſe are now called locomotive engines, and we may date their introduction with the patent of Meſſrs. Trevethick and Vivian in 1802, for the high-preſſure engines, which were expreſsly intended for working carriages. It would have been very difficult to have ſucceeded with any other kind of engine, as the weight of the water neceſſary to effect condenſation muſt be ſo great. Mr. Trevethick made a locomotive engine in South Wales in 1804, which was tried upon the rail-roads at Merthyr Tidvil. The engine was the ſame as that of which we have given an account of its work in ſpeaking of the high-preſſure engines, having an eight-inch cylinder, and a four-feet ſix-inch ſtroke. It drew after it, upon the rail-road, as many carriages as carried ten tons of bar-iron, for a diſtance of nine miles; and it performed all that diſtance without any farther ſupply of water than that contained in the boiler at ſetting out, travelling at the rate of five miles *per* hour.

Since that period they have been tried in many places upon rail-roads, but we do not think they had been really put in practice, ſo as to work conſtantly, until 1811, when Mr. Blinkinſop, proprietor of the Middleton coal-works, which ſupply the town of Leeds, adopted them for conveying the coals on his rail-road.

Mr. Trevethick's firſt engines conſiſted of a high-preſſure engine, with a boiler of caſt-iron, of a cylindrical form, ſix feet long, and four feet three inches diameter, the fire-place being withinſide. The cylindrical boiler was mounted horizontally upon four wheels, and the cylinder of the engine was placed vertically in the end of the boiler, having two connecting rods deſcending from the croſs-bar of its piſton-rod to two cranks, upon an axis extending beneath the boiler and cylinder, and communicating its motion, by means of wheel-work, to the two fore-wheels, upon which the engine runs; and by this means the alternate aſcending and deſcending motions of the piſton-rods act to turn round the crank and wheels, and draw the carriage forwards: in this way no fly-wheel was neceſſary, becauſe the momentum of the carriage to advance itſelf forwards on the road, continued the motion of the wheels and cranks ſufficiently to make the cranks paſs the lines of the centre. Where theſe engines were tried, it was found difficult to make the wheels take ſufficient hold upon the railway to draw any conſiderable load after it, unleſs the weight of the engine and work reſting upon the wheels was made very conſiderable, and then the common iron-rails of the railway were ſometimes broken by the paſſing of the engine.

Mr. Blinkinſop, when he adopted the locomotive engine, took up the common rails on one ſide of the whole length of the road, and replaced them with rails which had large and coarſe cogs projecting from the outſide. Theſe cogs are caſt at the ſame time with the rails, and are hollow beneath, to be as light as is conſiſtent with ſtrength and durability. The pitch of the cogs, or diſtance from centre to centre, is ſix inches, ſo that each rail, of three feet in length, has only ſix cogs. A wheel, which is fixed on an axis at one ſide of the carriage, works in the teeth of the rails; and as it is turned by wheelwork from the axis of the cranks, the whole machine is cauſed to advance along the railway. When we ſaw Mr. Blinkinſop's firſt trial, he employed a ſmall condenſing engine, but finding the water to grow ſo hot that he gained but little by the condenſation, he applied a high-preſſure engine with a wrought-iron boiler, and two cylinders in it acting upon ſeparate cranks, ſo as to produce a conſtant action to advance the carriage without the neceſſity of uſing a fly-wheel.

A ſimilar machine has been tried at Newcaſtle, but they have attempted to employ the wheels alone, without cogs upon the rails. To relieve the weight upon the rails, and obtain greater re-action to advance the carriage, they applied ſix wheels for the carriage to run upon; and to make the bearing equal upon all ſix, the two middle wheels were applied to the piſton of a ſmall cylinder beneath the carriage, into which ſteam was admitted, and by its preſſure bore up a portion of the weight of the engine; and accommodated itſelf to any inequalities of the railway.

At preſent, locomotive engines have been confined to moving upon iron-railways: to make ſteam-engines draw carriages upon public roads, is a refinement not yet attained.

In drawing up this article, we have derived conſiderable aſſiſtance from books, as our numerous references will teſtify; at the ſame time we cannot refer to any one work in the Engliſh language for a more detailed account of the ſteam-engine than we have here given. Many detached memoirs on particular points of the principle or conſtruction of the ſteam-engine, may be found diſperſed through the forty-ſix volumes of the Philoſophical Magazine, and the Philoſophical Journal. The firſt and ſecond volumes of the quarto ſeries of the latter work contain a ſketch of the hiſtory of the invention, but no particulars which are not given more at large in this article.

The Repertory of Arts, Manufactures, and Agriculture, conſiſting of ſixteen volumes of the firſt ſeries, and twenty-eight volumes, now publiſhed, of the ſecond ſeries, contains the ſpecifications of a great number of patents for inventions relating to the improvement of ſteam-engines, of which we have noticed nearly all in this article, which appeared to poſſeſs merit, or to have been ſucceſsfully put in practice.

The article *Steam-Engine* in the third edition of the Encyclopædia, which was written by Dr. Robiſon, is the beſt and moſt philoſophical view of the ſubject, but he has not entered at all into details: and as this was compoſed twenty years ago, the improvements made ſince that period, in the conſtruction of the machine, have made a total change.

The fulleſt account of the improved ſteam-engine is by the celebrated French engineer, M. Prony, who devotes the ſecond volume of his "Nouvelle Architecture Hydraulique," 1796,

expreſsly to that ſubject. He deſcribes four or five engines, with a great number of large plates, containing every detail of their conſtruction. The work is little more than a deſcription of the plates. Theſe engines are not the beſt ſpecimens of Mr. Watt's invention; they were all conſtructed in France by M. Perrier of Paris, who, in 1780, erected a large engine at Chaillot, to pump up the water of the Seine for the ſupply of the town, and another of ſmaller dimenſions on the oppoſite ſide of the river at Gros Caillou. Theſe engines are ſtill at work, and the writer of this article viſited them in 1814; they are upon the plan of Mr. Watt's firſt engines, though, for want of attention to ſome minute particulars, they do not produce any great effects. M. Perrier had viſited England to obtain the requiſite inſtructions for making theſe engines.

The double-acting engine of Mr. Watt was carried into France by M. Betancourt, whoſe experiments on the expanſive force of ſteam are referred to in this article. This gentleman came to London in 1788, with a view of collecting models of improved hydraulic machines for the court of Spain, and was admitted to examine the ſteam-engines made by Meſſrs. Boulton and Watt at the Albion Mills for grinding corn, which were the firſt large double-acting engines they had made. M. Betancourt has, in effect, made a kind of ſecondary claim to the invention of the double engine; for he informs us, that he ſaw in part the exterior conſtruction and operation of thoſe machines, but the interior mechaniſm was ſo concealed from him, as well as from others who had had the ſame curioſity before him, that he could only gueſs at the nature of the conſtruction. He obſerved, that the chains which are uſually applied to the extremities of the beam were ſuppreſſed, and that, inſtead of theſe, they had applied the parallel motion; that the different parts of the machine were ſo maſked by the diſtribution of the building, which iſolated even the exterior parts into different apartments, as to prevent him from comprehending their correſpondence; but, from the reſult of all his obſervations, he concluded the machine was of double effect.

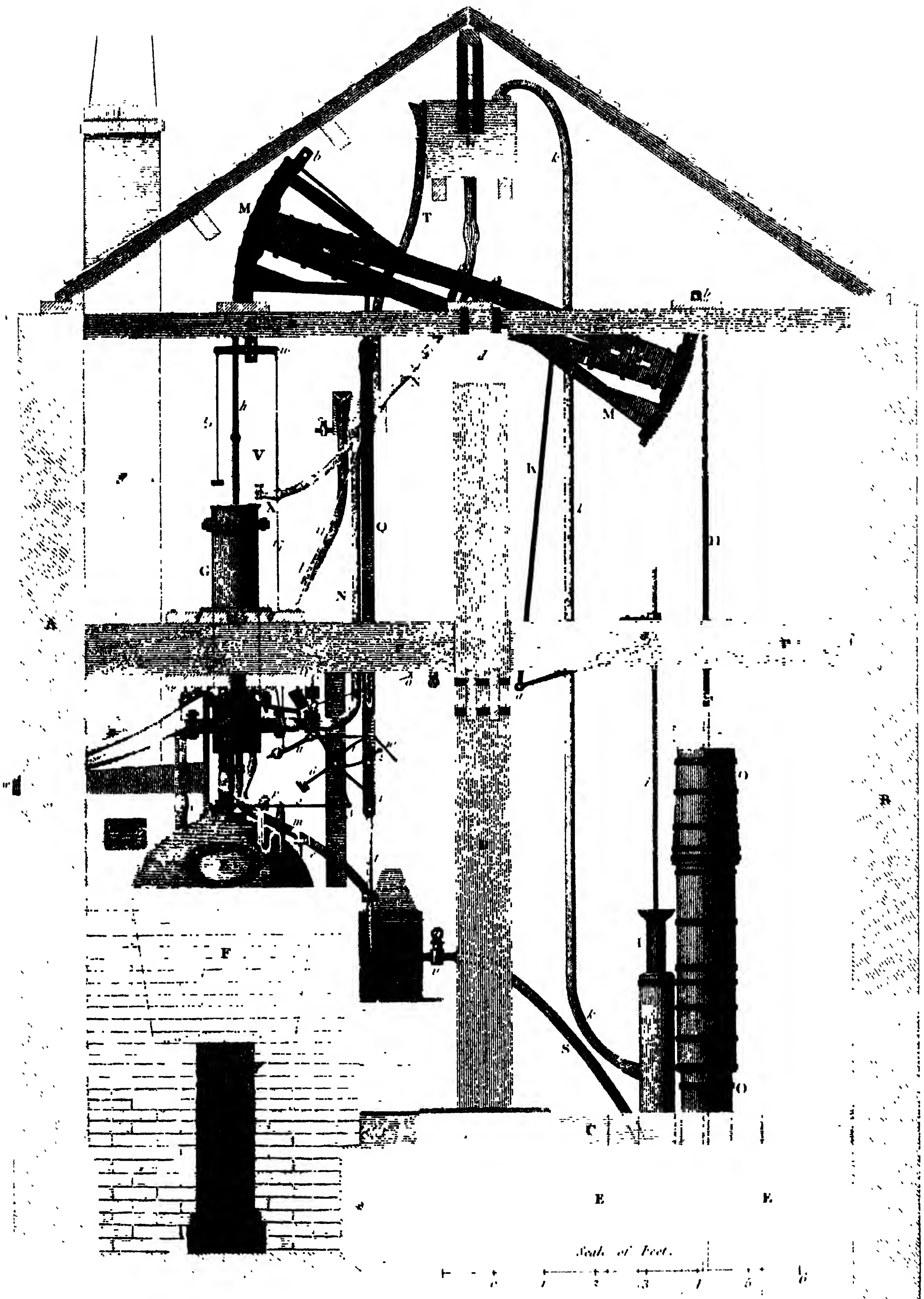
On returning to Paris, M. Betancourt made a model of a double cylinder, on a ſcale of an inch to the foot; and, as he did not know the arrangement of Meſſrs. Boulton and Watt's valves, he invented thoſe parts himſelf; and M. Perrier, from this model, conſtructed a large machine in 1790, at the iſle of Cygnes, in Paris, for grinding corn. By examining the conſtruction of this engine, which is fully deſcribed by M. Prony, it will appear that M. Betancourt made good uſe of his obſervations, for we find the engine to be the ſame as Mr. Watt's in every particular, except in the arrangement of the valves, which part is very defective, as both the ſteam-pipe and exhauſting-pipe muſt be filled with ſteam, and emptied at each ſtroke, in addition to the content of the cylinder, without producing any effect to work the engine. A different conſtruction by M. Betancourt, with two cocks, is alſo deſcribed, but it has the ſame defect, of which M. Prony was ſenſible; and in a ſecond machine which he deſcribes, points out the remedy, by varying the arrangement of the valves, ſo as to bring them very nearly the ſame as Mr. Watt's, though externally of different appearance. None of theſe engines have ſteam-jackets for the cylinders, nor is the expanſion principle mentioned by M. Prony. The beautiful contrivance of the regulation by the flying-balls is not deſcribed, but all the engines are regulated by a water-ciſtern and pump, which we have here deſcribed. See alſo REGULATOR.

It is to be regretted, that none of our experienced engineers have undertaken to write a work on ſteam-engines, as there is not any ſubject in mechanics ſo intereſting and uſeful.

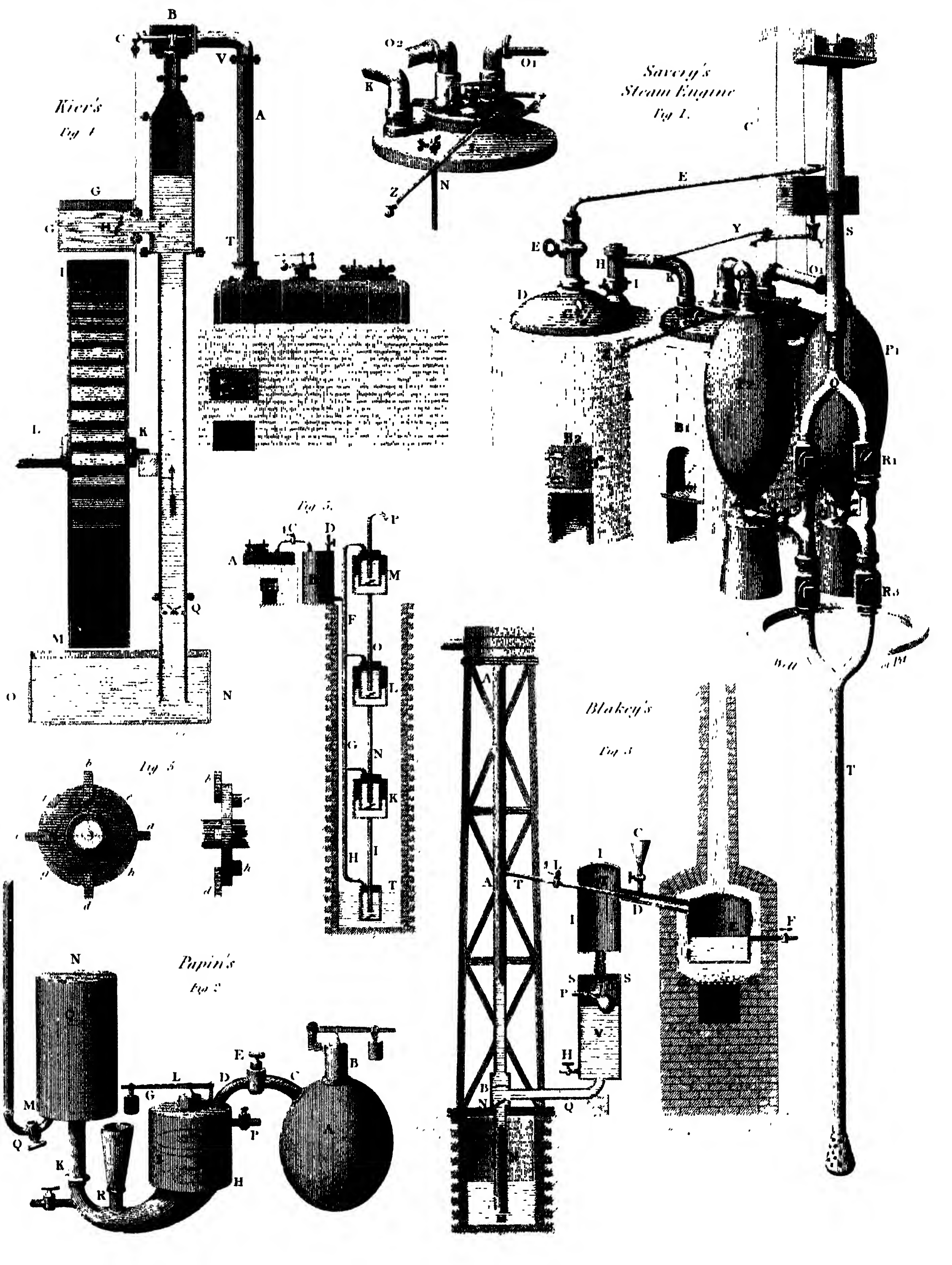
Almoſt every introduction to philoſophy contains a deſcription of the atmoſpheric ſteam-engine, and moſt of the modern ones a ſhort account of Mr. Watt's improvements; but theſe are in general very ſlight and defective; the beſt is in Brewſter's edition of Ferguſon's Lectures, which gives a ſketch of Mr. Watt's double engine, with the parallel levers and rotatory motion; and we believe it was the firſt deſcription publiſhed of that valuable invention, though it had been in general uſe for twenty-five years before. The engine is clearly deſcribed in the Britiſh Encyclopædia, 8vo.

STEAM ENGINE.

On the principle of Newcomen, as constructed by Smeaton.



Published as the Act directs, 181 by Longman Hurst Rees Orme and Brown Paternoster Row London

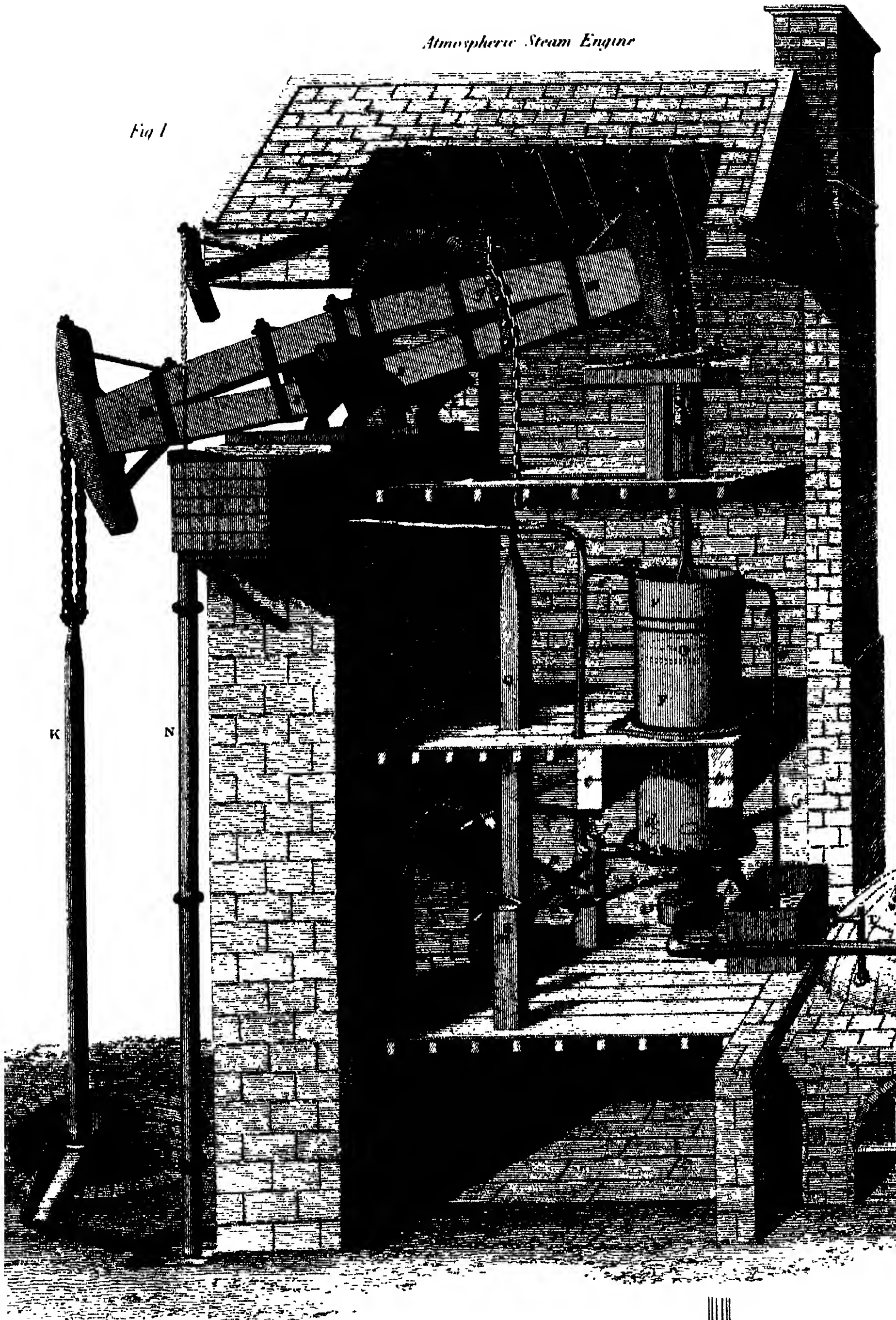


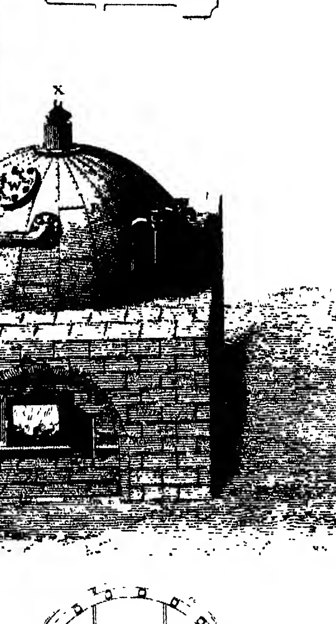
J. Farey delin
Published as the Act directs, 1810 by Longman Hurst Rees Orme & Brown, Paternoster Row

STEAM ENGINE.

Atmospheric Steam Engine

Fig 1





Regulator

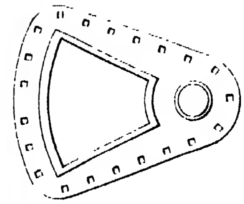
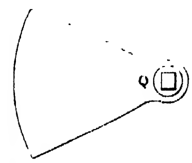
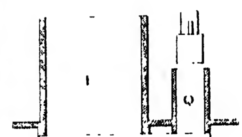


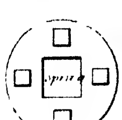
Fig 2.

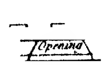


Section

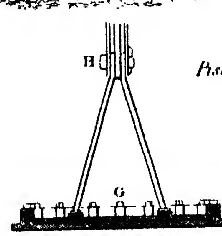


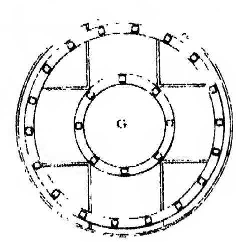
Injection Cap.
by Mr Smeaton





Piston

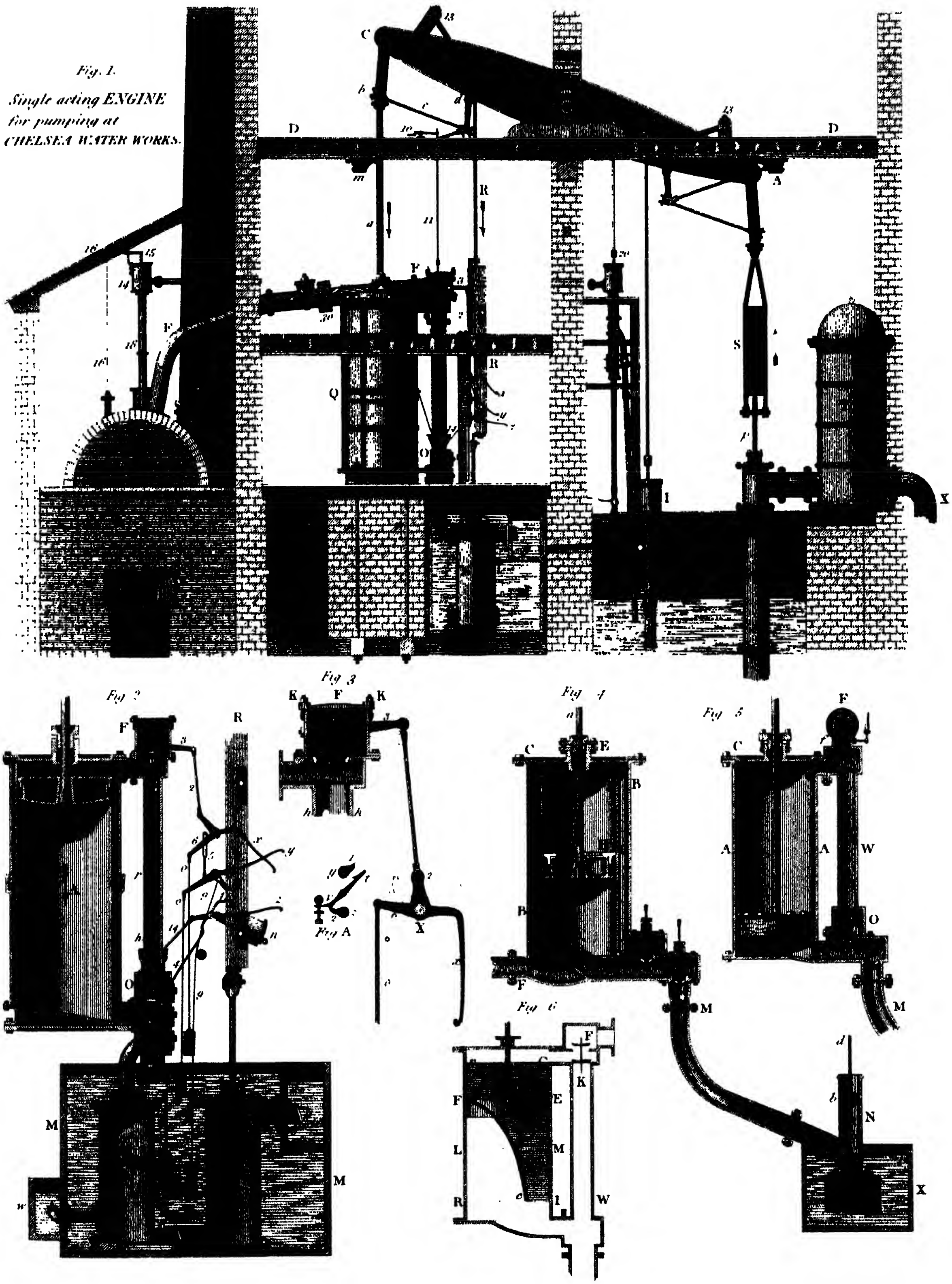




Published as the Act directs 1818 by Longman Hurst Rees Orme and Brown Paternoster Row London

STEAM ENGINE.

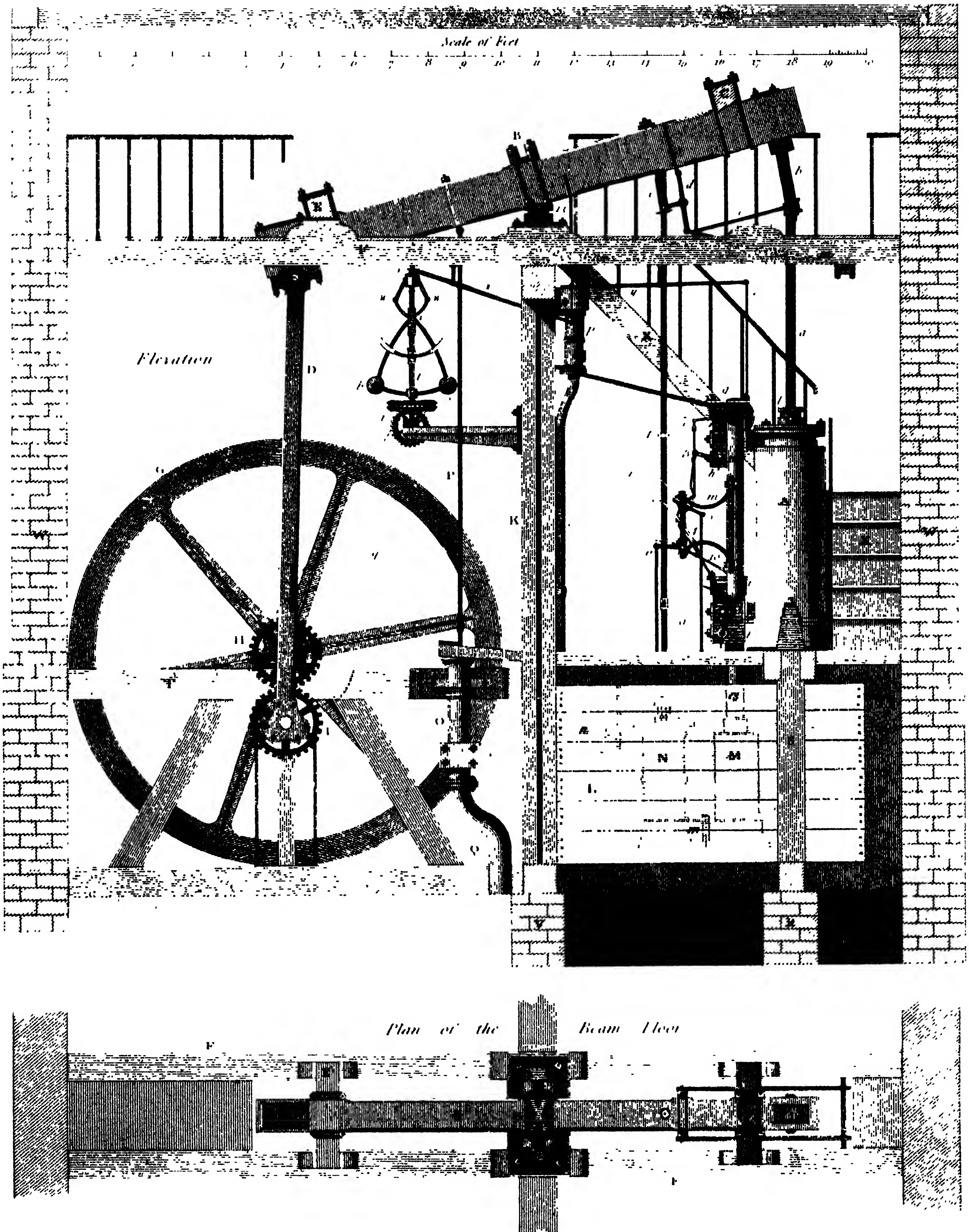
Mr. WATT'S ENGINE.



J. Farey delin. Published as the Act directs 1817 by Longman, Hurst, Rees, Orme & Brown Paternoster Row. Lowry sc.

STEAM ENGINE.

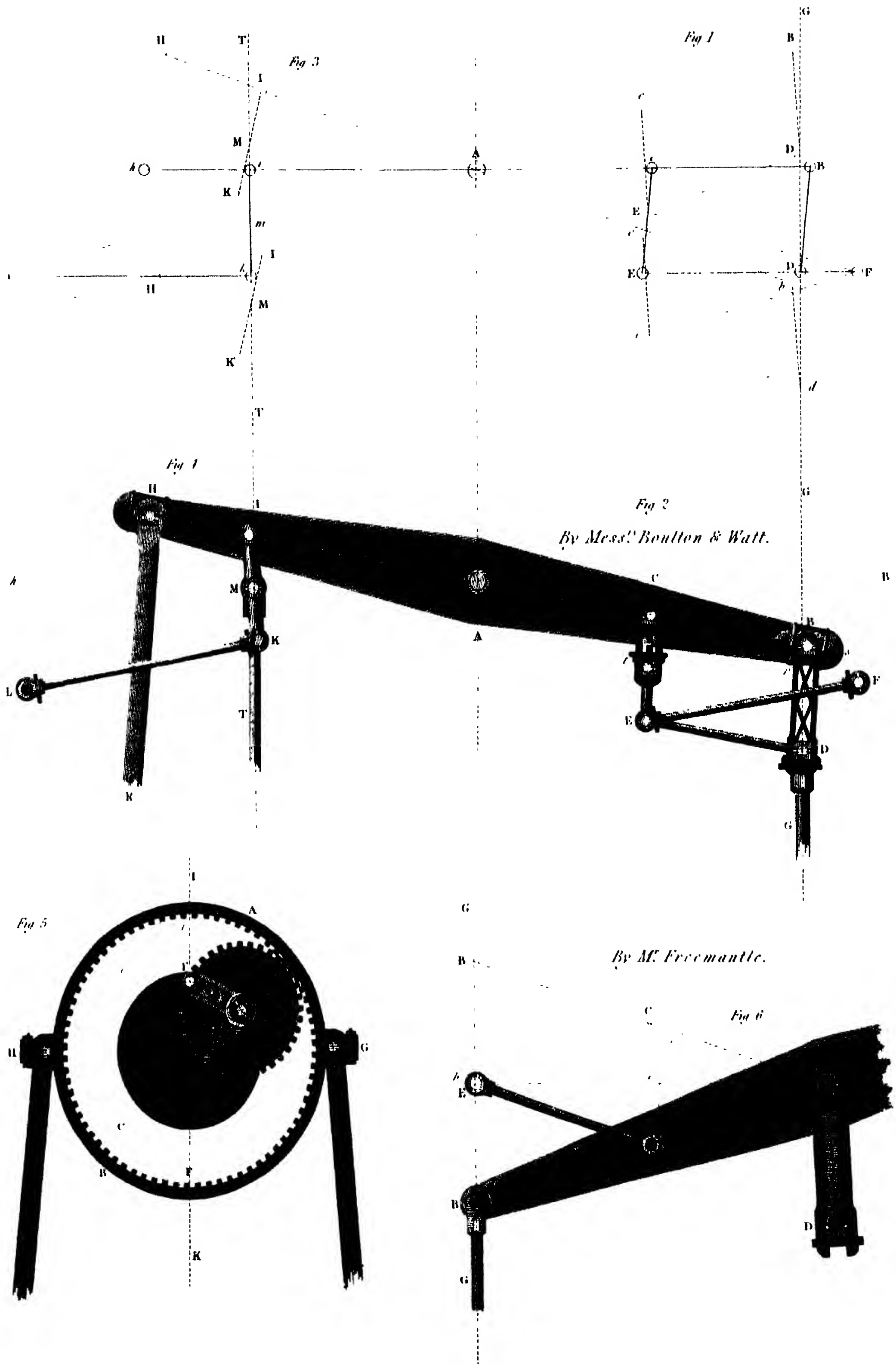
Boulton and Watt's Engine on the original Construction.



STEAM ENGINE.

PARALLEL MOTIONS.

PLATE III.



Farey Jun del *Published as the Act directs, by Longman Hurst Rees Orme and Brown, Paternoster Row, London* *Engraved by W Lowry*

STEAM ENGINE.

Fig..

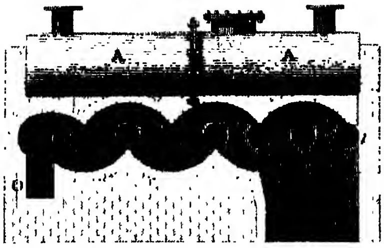


Fig 4

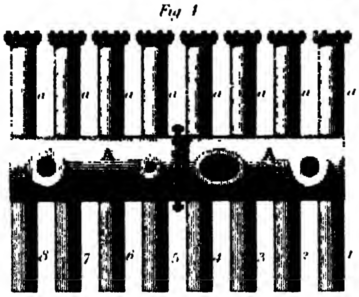
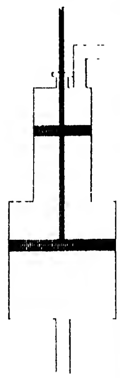
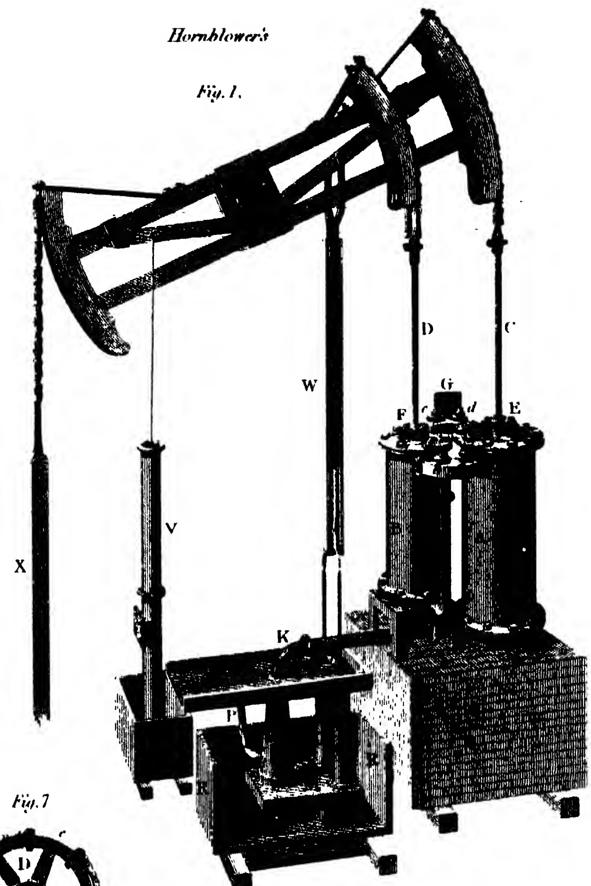


Fig. 2



Hornblower's

Fig. 1.



Cartwright's

Fig. 8.

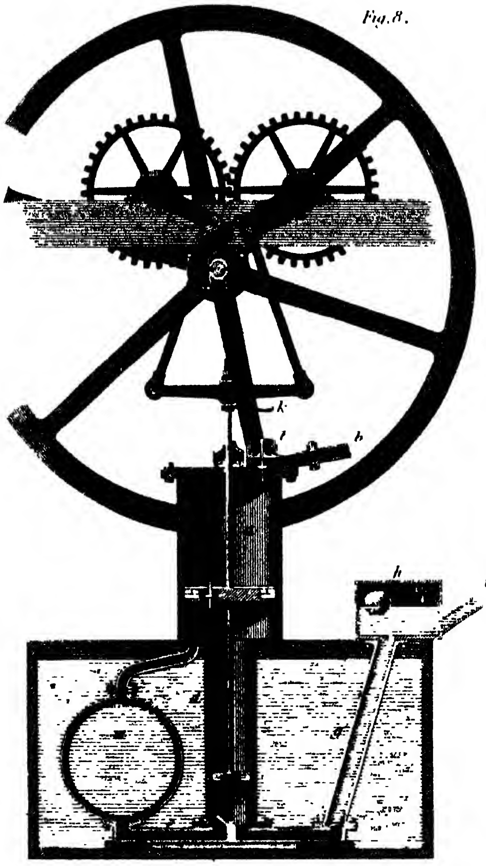


Fig. 7

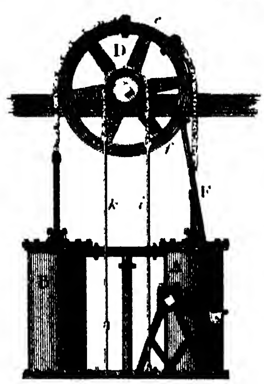
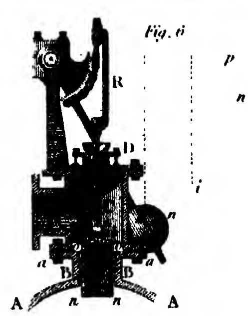
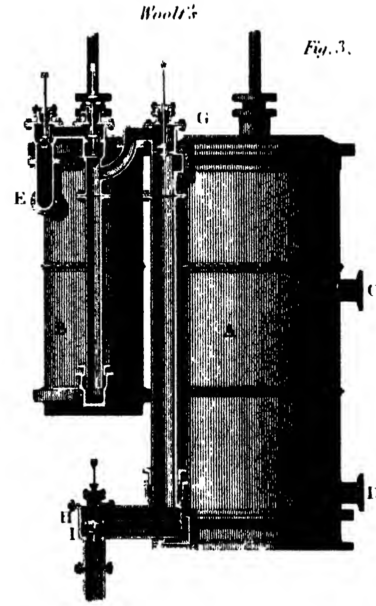


Fig. 6



Woolf's

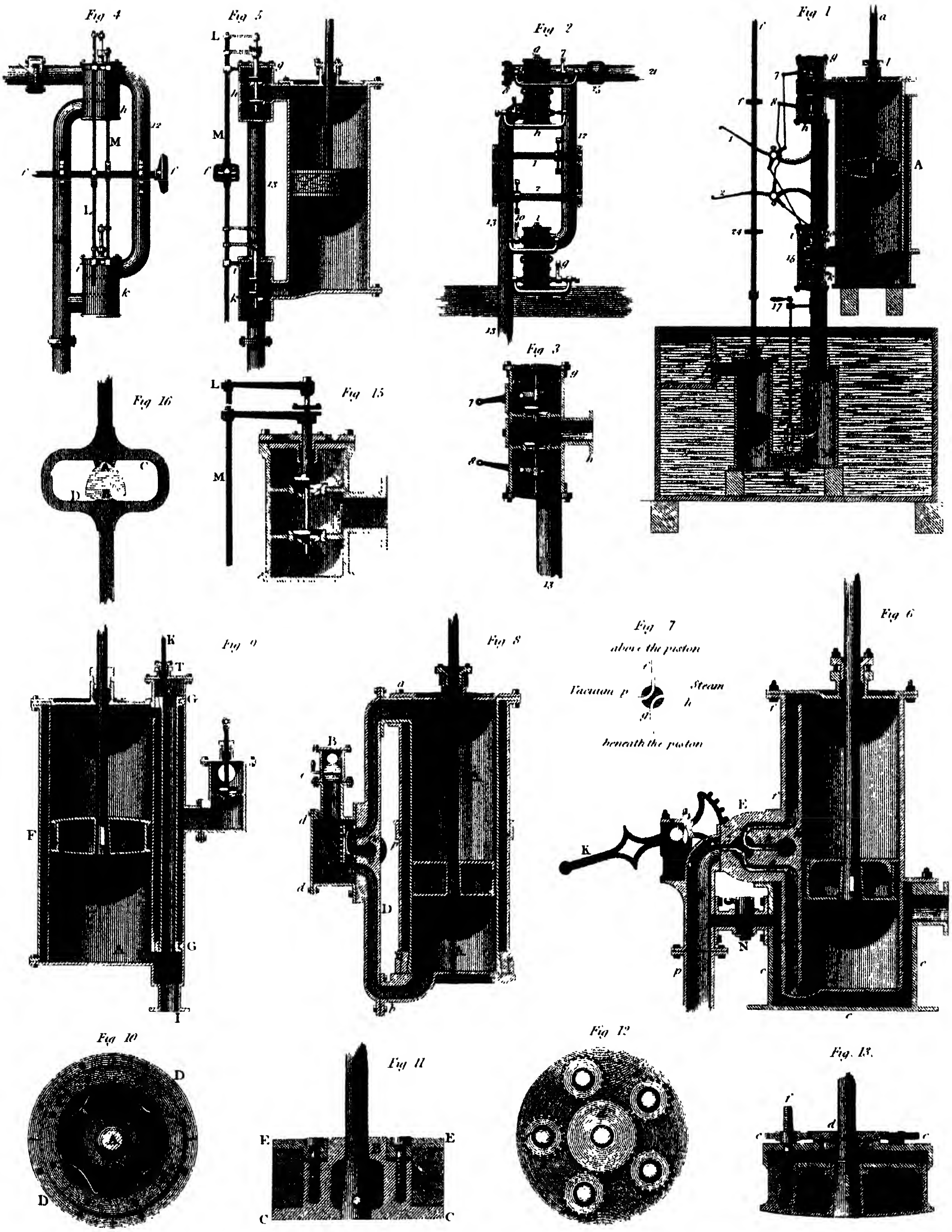
Fig. 3.



Published as the Act directs 1818, by Longman, Hurst Rees Orme & Brown, Paternoster Row, London

STEAM ENGINE,

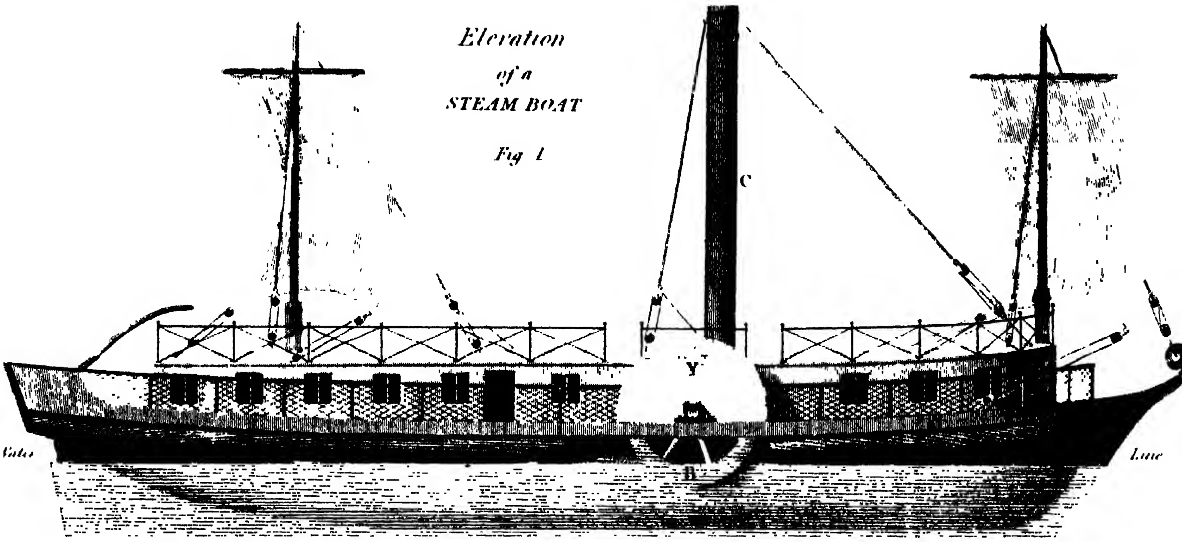
CYLINDERS, PISTONS &c



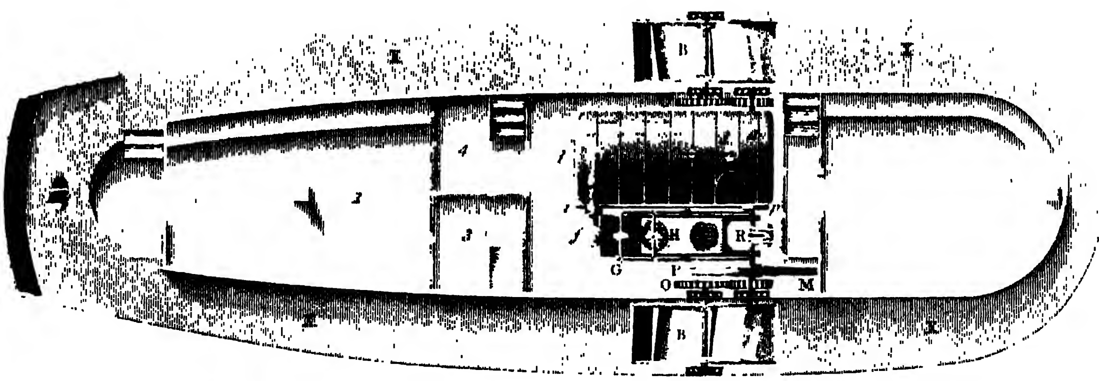
J. Farey delin   Published as the Act directs 1818, by Longman, Hurst Rees Orme & Brown Paternoster Row.   Lowry Sc.

Elevation of a STEAM BOAT

Fig 1



Plan Fig



Maudslay's STEAM ENGINE

Fig 3

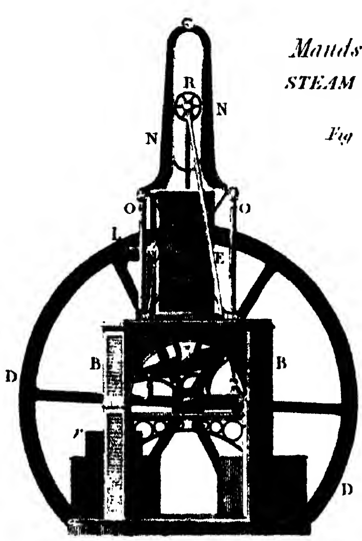
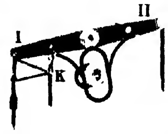
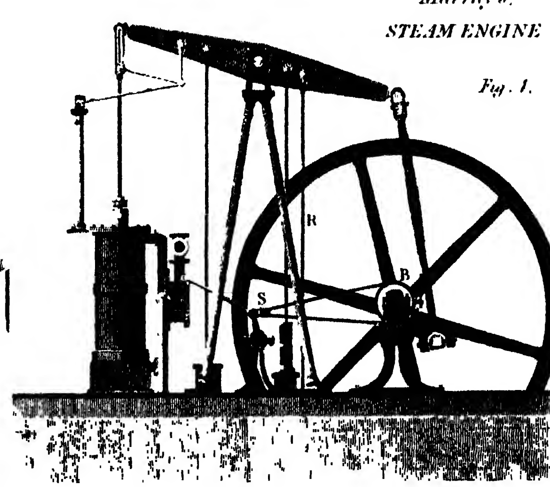


Fig 5



Murray's STEAM ENGINE

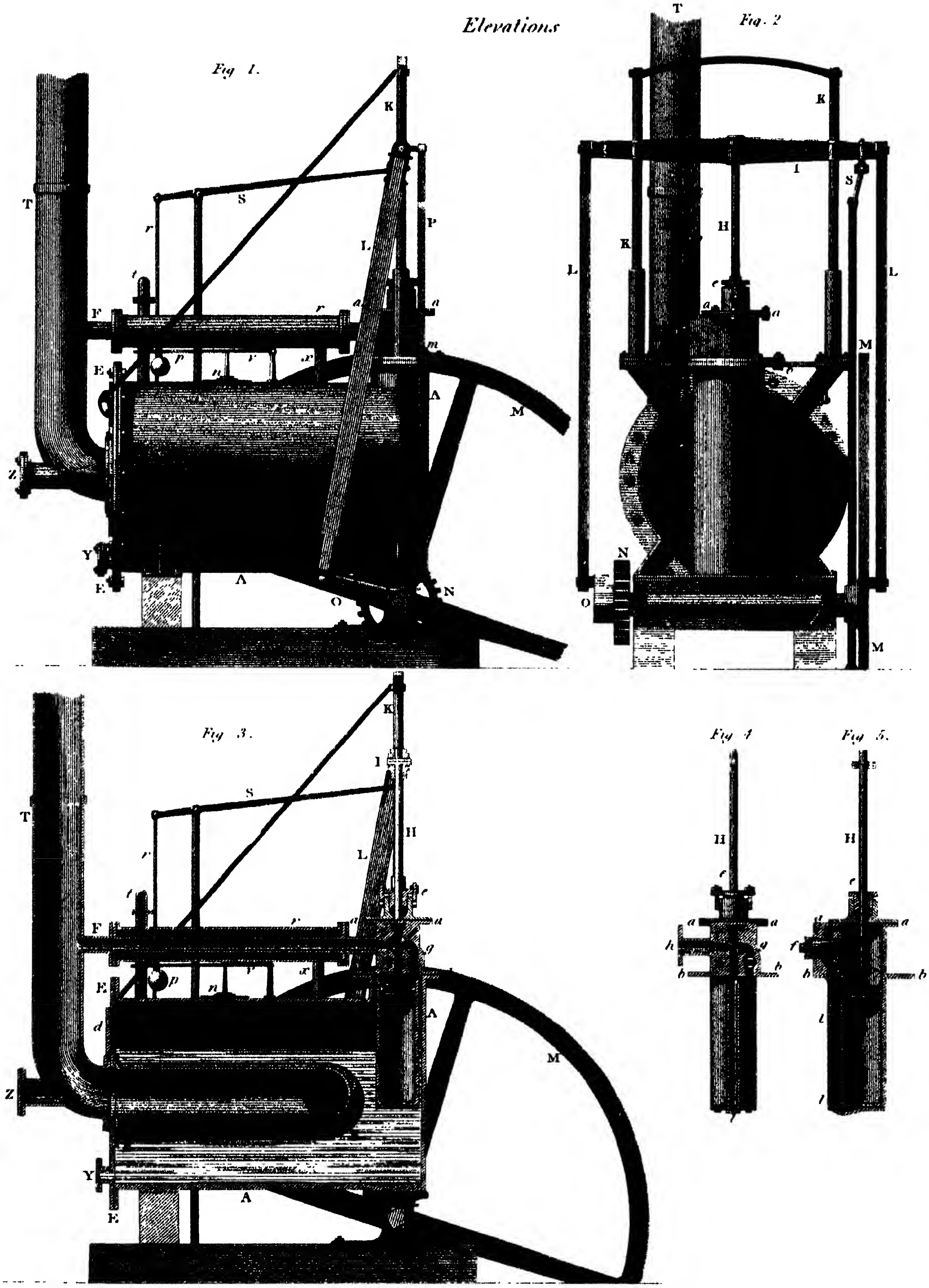
Fig. 4.



J Farey delin. Published as the Act directs, 1820, by Longman, Hurst, Rees Orme & Brown, Paternoster Row W. Lowry, sc.

High Pressure STEAM ENGINE used with the Dredging Machine on the River Thames.

Elevations



J. Farey Jun.r delin

Published as the Act directs, 1818, by Longman Hurst Rees, Orme & Brown, Paternoster Row

Lowry Sc.

Steel

STEEL, in the *Arts*, a most valuable metal, consisting of iron combined with carbon. It is chiefly used for edge-tools, and other cutting instruments, and from its fine polish is used in ornaments of various kinds.

In chemistry it is called a carburet of iron.

Its hardness is greater than that of iron; and its most valuable property is, that it can be made harder than any other metal, by suddenly cooling it when heated to redness: also, if it is heated to a lower temperature than redness, and suddenly cooled, it becomes the most elastic of all the metals. It is of a darker colour when polished, and retains its polish much longer, not being so liable to oxydate.

The specific gravity of steel is greater than that of iron: thus, the spec. grav. of cast-iron is .72070; malleable iron, .77880; steel in its soft state, .78404; hardened steel, .78180.

Steel is manufactured by two processes, one in which the steel is made from pig-iron at once in the finery: this is practised in Germany, and is called natural steel. Cemented steel is formed by stratifying bars of iron with powdered charcoal in a close vessel, and by keeping the mass at a brisk red heat for a longer or shorter time, depending upon the size of the bars. This process is called *conversion*. The test of the conversion being complete is its blistered appearance, from which it has been called *blistered* steel. As the steel in this change does not undergo fusion, all the imperfections in the mechanical texture of the iron will still be found to exist in the steel. A drawing of the furnace employed for this process is given in *Plate* VII. *Iron Manufacture;* for the references to which, as well as the mill for tilting steel, see TILTING *of Steel.* It is from blistered steel that all the different kinds of steel are manufactured. These are principally of two varieties, *viz. cast-steel* and *shear-steel.*

Cast-steel is blistered steel fused and cast into ingots, which are afterwards drawn into rods by the hammer or by rolling. By this change the steel becomes much harder, and of course entirely free from those seams and other defects which exist in the blistered steel: this is what renders cast-steel so much better for polished goods: for when blistered steel is attempted to be polished, the surface is seen to abound with numerous spots, arising from mechanical defects in the bars previous to conversion.

Cast-steel works much harder under the hammer, and will not bear much more than a red heat, without breaking in pieces under it. This, however, is more especially confined to that commonly made; since cast-steel may be made which will bear a white and even a welding heat; but it requires a much greater heat for its fusion, and would in consequence be sold at a higher price.

The refuse of blistered or common steel is generally melted into cast-steel; but this is not of the best quality. The best cast-steel is made by melting the bars of blistered steel, which, for this purpose, are a little more converted than for ordinary purposes, in order to give the steel a little more carbon than if it were used in the state of blistered steel. The bars are broken into small pieces, for the purpose of stowing the greatest quantity in the crucible.

The furnace employed for melting of steel is the best constructed air-furnace, and is similar in form to those used by brass and iron-founders in the small way, where the crucible is employed. That part of the furnace containing the crucible and the fuel is of a prismatic form, about twelve inches square, and two feet in length from the grate to the top where the cover is placed. About three inches below the cover is a horizontal opening, called the throat of the furnace, which leads directly into the chimney. This opening is about three inches by six, and must never be less than the open part of the grate. In some manufactories, ten or twelve of these furnaces are at work at one time. The mouths of the furnaces are level with the floor of the room where the casting is performed. These are arranged along the two opposite walls, each containing a stack of high chimnies. The ash-pits of these furnaces terminate in a cellar below, which is well supplied with air. The crucibles in which the steel is melted are made on the spot. The material is Stourbridge clay, to which a little coke-dust is added. They are formed in a mould of cast-iron, of the form of the outside of the crucible. The proper quantity of tempered clay is first put into this mould, and then a wooden plug is driven in to form the inside of the crucible. They are then gradually dried, and slightly baked, at a much less heat than is given to the softest pottery. The crucible is generally removed from the baking fire to the furnace, which would be liable to crack if put into the fire cold. The crucible is placed upon a stand about four inches high, which is also placed upon the middle of the grate. The base of this stand is less in diameter than the upper part, in order to intercept the air the least possible. Each crucible is also provided with a flat cover, made very true on the under side, so as to fit. It is a little larger than the top of the crucible, in order to be easily removed with tongs. The cover is generally made of fire-clay a little more fusible than that of the crucibles. This admits of as much vitrification between the cover and the crucible, before the melting of the steel, as serves to keep out the air, which, at this high temperature, would injure the quality of the steel, by first destroying its carbon, and then oxydating the iron. In order, however, to guard more completely against this evil, some make use of what is termed a flux. This consists of any easily vitrifying substance, such as bottle-glass, in very small quantity. The substance now employed is the blast-furnace cinder.

The fuel used for melting steel is the coke of pit-coal, very highly baked in kilns used for the purpose. The fracture of these cokes is white and brilliant. They are so hard as to be sonorous; and their specific gravity is much greater than ordinary cokes. This coke, being broken into pieces about the size of an egg, is made to surround the crucible closely on all sides, and a few inches above the same. The heat required to melt steel is so intense, that if the fuel were not firm and dense, the fire would not last till the fusion took place. This would require a supply of cold fuel, which would not only endanger the crucible, but occasion great delay. When the steel is thoroughly fused, the crucible is withdrawn with a pair of long tongs, opening with two concave jaws to fit the cylindrical form of the crucible. The tongs are not removed till the metal is poured. Immediately on bringing it out of the fire, previous to which the cover is removed, some scoria, or refuse arising from the flux, is first removed. This exposes the steel to the action of the oxygen of the atmosphere. Particles of the metal are now seen to dart out of the crucible in bright corruscations, and these continue all the time the metal is pouring into the mould, causing a grand and interesting appearance. The mould is

of caſt iron, giving an octagonal ſhape to the ingot. Theſe moulds are of various forms. Thoſe uſed for ſteel-plate are in the form of parallelograms: and thoſe for making large ſaws are ſmaller at each end, in order to roll out into a plate nearly of the form of the ſaw.

The ſteel known by the name of ſhear-ſteel, has been ſo called from its application to the cutting part of ſheep or wool ſhears. It was formerly manufactured at Newcaſtle-upon-Tyne, and has been called Newcaſtle ſteel. From being ſubjected to a ſimilar proceſs to the natural ſteel made in Germany, it has alſo been termed German ſteel.

We have before obſerved, that the bar-iron of which ſteel is made, contains many defects in its mechanical texture. In this ſtate, it is ſaid by the workmen to be looſe, and is more or leſs ſo, as depending upon the management of the bar-iron maker. The manufacture of ſhear-ſteel conſiſts in removing theſe defects, and at the ſame time giving it what is called increaſed fibre by the operation of hammering.

The firſt preparation is to lay a number of bars of bliſtered ſteel together, and bind them with iron rings at one end, ſo that the bars which are put in the fire may not be diſplaced. A portion of theſe united bars is now to be heated to a full welding heat, keeping the ſurface well defended by throwing powdered ſand upon it from time to time. This fuſes with the oxyd of iron, forming a liquid coating, which defends the ſurface from the action of the air. If this precaution is not obſerved, the ſteel, when heated to the degree of welding, would become what is termed *burnt*, and its malleability be impaired. In the welding ſtate it is placed under a forge-hammer, working by water or a ſteam-engine; when the bars become firmly united, and all the looſe parts previouſly exiſting in the malleable iron are at the ſame time made ſound. When a little more than half the length of the bars is treated in this way, the iron rings are removed, and the other end heated and hammered in a ſimilar way. The welded maſs is now drawn down into ſmall bars about an inch and a quarter broad, and three-eighths or half an inch in thickneſs. In this ſtate it is ſold to the conſumer, who afterwards has it reduced to different ſized rods by the tilt-hammer. The ſteel is rendered ſo compact in texture by the welding and hammering, as to become ſuſceptible of a much better poliſh than bliſtered ſteel is capable of; at the ſame time that its tenacity and malleability are much improved. The former improvement highly fits it for table-knives: the latter makes it valuable for ſprings of various kinds, particularly thoſe of gun-locks.

The proceſs by which this ſteel is formed has another advantage beſides rendering it ſound and more malleable. It is found ſofter and more kind than the bliſtered ſteel from which it is formed, and is much more uniform in its quality. This may be explained by the fact, that a quantity of the carbon of the bliſtered ſteel is diſſipated in the form of carbonic acid during the welding and hammering, by which a ſteel is obtained, having a leſs than ordinary proportion of carbon, and is in conſequence leſs liable to break in bending, and at the ſame time ſofter and more flexible. Indeed, if the proceſs of welding and hammering were repeated ſeveral times, the ſteel would loſe the whole of its carbon, and become pure iron.

Bliſtered ſteel ſhould not be uſed but for the commoneſt purpoſes, where great tenacity of poliſh is not an object. For all nice purpoſes, where great tenacity and ſoundneſs are neceſſary, ſhear-ſteel ſhould be employed; and where a fine poliſh or great hardneſs is wanted, caſt-ſteel is indiſpenſable. See IRON and CUTLERY.

STEEL, *Annealing*, or *Nealing of*, is for the ſoftening it, in order to make it work eaſier; which is uſually done by giving it a blood-red heat in the fire, and then taking it out, and letting it cool of itſelf.

Some have pretended to ſecrets in annealing, by which they could bring down iron or ſteel to the temper of lead: this was to be done by often heating the metal in melted lead, and letting it cool again out of the lead. But this method has no other effect than what is obtained from the former, when the cooling is very gradual.

Steel may indeed be made a little ſofter than in the common way, by covering it with coarſe powder of cow-horn, or hoofs: thus incloſing it in a loam, heating the whole in a wood-fire till it be red-hot, and then leaving the fire to go out of itſelf, and the ſteel to cool, which it will do ſlowly from being incloſed. See TEMPERING, and STEEL, *ſupra*.

For the expanſion of ſteel by heat, ſee PYROMETER.

STEEL-*Glaſſes*, a name given by ſome authors to the metalline ſpheres uſed in optics. Theſe, according to Cardan, are made of three parts of braſs, one part of tin, and one of ſilver, with an eighteenth part of antimony; but moſt either totally leave out the ſilver, or add only a twenty-fourth part, to ſave the expence. There are many other methods, directed by ſeveral authors, but moſt uſe arſenic and tartar, mixed with the metals. Theſe are afterwards to be poliſhed with emery, rotten-ſtone, putty, and the like.

STEEL-*Ore*, is uſed to ſignify a particular kind of lead-ore.

Stereotype Printing

STEREOTYPE PRINTING. This art having of late years come very much into uſe, we ſhall give a ſhort ſketch of its *hiſtory*, *practice*, and *advantages*.

The method of printing linen and paper-hangings has been known in the Eaſt from time immemorial. Printing on wooden blocks, which is the mode now uſed by paper-ſtainers, has been practiſed fifteen or ſixteen hundred years in China. According to this plan, when an author means to print his work, he has it fairly tranſcribed upon a thin and ſemi-tranſparent paper. Each leaf is then reverſed upon a ſmooth block of hard wood, upon which the engraver cuts the characters in relief. There muſt, therefore, be a ſeparate block for every page. About the cloſe of the 14th century, the Italians, Germans, Flemings, and Dutch, began about the ſame time to engrave on wood and copper, but the previous advances had been gradual. The inſcriptions in relief, upon monuments and altars, in the cloiſters, and over church porches, ſerved as models for block-printing. The letters upon painted windows reſemble thoſe in the books of images. The invention of cards was probably an intermediate ſtep; and it has been inferred, as well from edicts civil and eccleſiaſtical, as from the figures on the cards, that theſe were firſt brought into uſe about the year 1376, to amuſe, it is ſaid, Charles V. of France. By the ſhape of the crowns, and the ſceptres with the fleur-de-lis, it has been thought they were invented by the French; but the names of the ſuits rather imply, that they are of Spaniſh or Italian origin. At firſt cards were painted, but about the year 1400, they were printed from wooden blocks. To this we may directly trace the art of printing. The books of images, which form the next ſtep, were printed on wooden blocks: one ſide of the leaf only is impreſſed, and the correſponding text is placed below, or on the ſide, or proceeding from the mouth of the figure. Of theſe ſcarce books, Lambinet gives the following enumeration: 1. "Figuræ typicæ veteris atque antitypicæ Novi Teſtamenti," which in Germany is called the Bible of the poor, becauſe it was originally intended as an abridgment of the ſcriptures, for thoſe who could not purchaſe, or who had not leiſure to read the whole. There is a copy of this work in the Bodleian library, and another at Chriſt's college, Cambridge. 2. "Hiſtoria S. Joannis Evangeliſtæ, ejuſque viſiones evangeliſtæ, ejuſque viſiones apocalypticæ." 3. "Hiſtoria ſeu Providentia Virginis Mariæ, &c." 4. "Ars moriendi." 5. "Ars memorandi notabilis per figuras Evangeliſtarum." 6. "Donatus, ſeu grammatica in uſum ſcholarum conſcripta." 7. "Speculum humanæ ſalvationis."

It is almoſt certain, therefore, that from the cotton and ſilk-printing of the Indians, the Chineſe block-printing, and the books of images juſt alluded to, and perhaps from the mode of writing among the bards, who cut their poems upon bars of wood, and which they call carving a book, the idea of ſtereotype printing is not of modern origin. That it was prior to the art of printing by moveable types there can be no doubt, ſince this latter mode of printing was firſt ſuggeſted by the Catholicon, which was printed with wooden tablets, in a ſeries, and compoſed in forms. This mode of printing, except in China, where it is ſtill practiſed, was laid aſide ſoon after the invention of the common letter-preſs printing.

The hiſtory of the modern ſtereotype is involved in ſome obſcurity. In the Philoſophical Magazine is the following account: "Above a hundred years ago, the Dutch were in poſſeſſion of the art of printing with ſolid or fixed types, which were in every reſpect ſuperior to that of Didot's ſtereotype. It may, however, be eaſily underſtood, that their letters were not cut in ſo elegant a manner, eſpecially when we conſider the progreſs which typography has made ſince that period. Samuel and J. Leuchtmans, bookſellers at Leyden, have ſtill in their poſſeſſion the forms of a quarto bible, which were conſtructed in this ingenious manner. Many thouſand impreſſions were thrown off, which are in every body's hands, and the letters are ſtill good.

"The inventor of this uſeful art was J. Vander Mey, who reſided at Leyden about the end of the 16th century. With the aſſiſtance of Muller, the clergyman of the German congregation there, who carefully ſuperintended the correction, he prepared and caſt the plates for the above-mentioned bible, in 4to. This bible was publiſhed likewiſe in folio with large margins, ornamented with figures, the forms of which are ſtill in the hands of Elwe, a bookſeller at Amſterdam; alſo an Engliſh New Teſtament, and Schaaf's Syriac Dictionary, the forms of which were melted down: likewiſe a ſmall Greek Teſtament, in 18mo. As far as can now be aſcertained, Vander Mey printed nothing elſe in this manner; and the art of preparing ſolid blocks was loſt at his death, or at leaſt was not afterwards employed." The Dutch editor ſuppoſes, that the reaſon why Vander Mey's invention was dropped was, that the proceſs was too expenſive.

In the year 1781 was printed, by Mr. Nichols of London, a pamphlet, entitled "Biographical Memoirs of William Ged," including a particular account of his progreſs in the art of block-printing. The *firſt* part of the pamphlet was printed from a MS. dictated by Mr. Ged juſt previouſly to his death: the *ſecond* part was written by his daughter, for whoſe benefit the profits of the publication were intended: the *third* is a copy of propoſals iſſued by Ged's ſon, in 1751, for reviving his father's art; and to the whole is added Mr. More's narrative of block-printing. It ſhould ſeem from this publication, that in the year 1725, Mr. Ged began his ſcheme of block-printing. In 1727 he entered into a contract with a perſon who had a ſmall capital, but who, alarmed at the ſuppoſed riſk of loſing the little which he had, abandoned the concern, after he had expended little more than twenty pounds. In 1729 he entered into a more promiſing partnerſhip with a Mr. Fenner, Mr. Thomas James, a type-founder, and John James, an architect. Some time after a privilege was obtained from the univerſity of Cambridge to print bibles and prayer-books; but it appears, that one of his partners was actually averſe from the plan, and, to thwart the project, engaged ſuch people for the work as he thought moſt likely to ſpoil it. One of his people who was entruſted with the ſecret, avowed, that all the books printed in ſtereotype had been purpoſely made incorrect, in conſequence of which they were ſuppreſſed at the univerſity, and the plates ſent to the king's printing-houſe, and from thence to Caſlon's foundery. "After much ill uſage," ſays the

writer in the Philofophical Magazine, "Ged, who appears to have been a perfon of great honefty and fimplicity, returned to Edinburgh. His friends were anxious that a fpecimen of his art fhould be publifhed, which was done by fubfcription. His fon James, who had been apprenticed to a printer, with the confent of his mafter fet up the forms in the night-time, when the other compofitors were gone home, for his father to caft the plates from, by which means Salluft was finifhed in 1736." A copy of this work is in Mr. Tilloch's poffeffion, and alfo a plate of one of the pages from which it was printed. Another work was alfo printed from plates manufactured by Mr. Ged; this was the well-known book entitled "The Life of God in the Soul of Man," which has the following imprint; "Newcaftle, printed and fold by John White, from plates made by William Ged, goldfmith in Edinburgh, 1742."

Fifty years after the invention of plate-printing by Mr. Ged, Mr. Tilloch tells us he made a fimilar difcovery, without having at the time any knowledge whatever of Ged's invention. He was aided in bringing his difcovery into practice by Mr. Foulis, printer to the univerfity of Glafgow. They overcame every difficulty, and were able to produce plates, the impreffions of which were as perfect and handfome as thofe of the types from which they were caft. Though we had reafon to fear, fays Mr. Tilloch, from what we afterwards found Ged had met with, that our efforts would experience a fimilar oppofition, we perfevered in our object, and took out patents for England and Scotland, to fecure to ourfelves, for the ufual term, the benefits of our invention; for the difcovery, he adds, was as much their own, as if nothing fimilar had been practifed before. Ged's knowledge of the art may be faid to have died with his fon, whofe propofals for reviving it, publifhed in 1751, not having met with encouragement, he went to Jamaica, where he died. Owing to circumftances of a private nature, not at all connected with the ftereotype art, the bufinefs was laid afide after fome few volumes had been ftereotyped and printed under the direction of Meffrs. Tilloch and Foulis.

Some time elapfed, when M. Didot, a French printer, applied the ftereotype art to logarithmic tables, and afterwards to feveral of the moft popular claffics, fuch as Virgil, Horace, &c. and to various French publications. On this account, the French lay claim to the invention, but furely without even the appearance of juftice. About the year 1800, Mr. Wilfon, a printer in London, engaged with earl Stanhope, for the purpofe of bringing the ftereotype art into general practice. His lordfhip is faid to have had fome communications with Mr. Tilloch on the fubject, and afterwards to have received the perfonal attendance of Mr. Foulis at his feat, at Chevening, in Kent, where the noble earl was probably initiated into the practical part of the operation, and for which, we have heard, he paid 700*l.* as a remuneration.

After fome years application, Mr. Wilfon, who at that time lived in the neighbourhood of Lincoln's-Inn-Fields, but who afterwards removed to St. Pancras, and carried on the bufinefs on a very extenfive fcale, announced to the public, that the genius and perfeverance of earl Stanhope had overcome every difficulty; and that accordingly, the various proceffes of the ftereotype art had been fo admirably contrived, combining the moft beautiful fimplicity, with the moft defirable economy, the *ne plus ultra* of perfection, with that of cheapnefs, as to yield encouragement to the public for looking forward to the happy period when an application of this valuable art to the manufacture of books would be the means of reducing the price of all ftandard works, at leaft thirty, and in many cafes forty, *per cent.*

In 1804, Mr. Wilfon offered, upon certain terms advantageous to himfelf, the ftereotype art to the univerfity of Cambridge, for their adoption and ufe in the printing of bibles, teftaments, and prayer books. Some differences between the fyndics and the printer caufed the contract to be diffolved. Into thefe difputes it is not our bufinefs to enter; it will be fufficient to add, that at prefent, at Oxford as well as at Cambridge, the ftereotype art is adopted, and thoufands of bibles, &c. iffue annually from their preffes, printed on that plan.

The practice of ftereotype printing is readily defcribed: a page of any work is fet up in the ufual mode of printing, (fee the article PRINTING,) from which a mould of plafter, fimilar to plafter of Paris, is taken off, and from this a plate in type metal, from which the ftereotype print is worked. Of courfe the whole is fet up in diftinct pages, which are to be put together in the ufual way before a fheet is worked at prefs.

It is evident, therefore, that the beautiful fpecimens of ftereotype printing fometimes exhibited, and which have induced many perfons to afcribe that merit to the art, does not in reality belong to it. A ftereotype plate is a fac fimile of the page from which it was taken, and confequently cannot exceed in beauty the original type. Stereotype, therefore, can give no additional beauty to printing: this depends on the tafte of the letter-founder, and the care of the preffmen. Thofe who produce fine fpecimens of ftereotype printing, could alfo give others equally good with the moveable types from which the plates are caft.

The metal of which the plates are to be caft is a compound of regulus of antimony and hard lead, or tea-cheft lead. The general method of mixing the metal is to take one hundred weight of regulus of antimony, and break it into fmall pieces, feparating from it all duft and dirt, and then add to it from five to eight hundred weight of hard lead, according as the metal is required to be more or lefs hard. The lead is to be melted over a flow fire, and when melted, and the fcum taken off, the regulus is to be put in. To every hundred weight of lead may be added a pound or two of block-tin, but this is not neceffary.

In cafting the plates, as in every other cafting, a mould muft firft be made, fo as to form the counterpart of the original type. The fubftance required for this muft be of fo delicate a texture when foft, as to be capable of receiving an impreffion from the fineft lines: and when dry, it muft be capable of bearing the action of melted metal. Thefe qualities will be found in gypfum or plafter of Paris. Gypfum in the rock, as it is called, which is the beft, is plentiful in Nottinghamfhire. It has been obferved, that this fubftance, when pulverized and mixed with water, foon becomes very hard, and will bear almoft any degree of heat; but it contracts when expofed to fire, and is liable to warp. It is alfo extremely difficult to expel the air and moifture which it rapidly abforbs, and tenacioufly retains. Thefe are defects refpecting the procefs of cafting, which require to be corrected by compounding it with other fubftances lefs abforbing than itfelf. But whatever be added to it muft be capable of a fine furface, fo as to preferve a perfect polifh on the plate to be caft. The following procefs has been recommended: diffolve a quantity of common whiting in a tub of clean water, and make it of the confiftence of what is generally ufed in white-wafhing. Mix the plafter with this folution, and it will contract but little from the heat; the air and the moifture will be expelled with greater eafe,

and the mould will not be fo liable to crack as the plafter would alone.

In making a perfect mould for the page to be caft, a frame of caft-iron muft be prepared, nearly half an inch wider and longer than the page or pages locked up in the chafes. The frame determines the thicknefs and ftrength of the mould, and requires to be nearly an inch deep. To this muft be added four cubic pieces of metal, whofe height fhould be exactly four-fifths of the height of the letters. On the height of thefe, the thicknefs of the ftereotype plate depends. The pages in the chafes are now to be laid flat upon the moulding table, and the letter, if neceffary, is to be planed down to an even furface. In the openings of the four corners of the page are to be placed the four pieces of metal, on which the frame is to reft when laid over the page.

To prevent the adhefion of the plafter, it will be neceffary to oil the face of the page with a foft brufh; then take a quantity of the white-wafh into a wooden bowl, and add to it fo much fine plafter as will make it into a thin pafte. When reduced to an equal confiftency, apply it to the face of the letter with a painter's brufh, fo as to fill every cavity, and then pour on the remainder of the plafter to fill the frame. When beginning to harden, ftrike off the fuperfluous plafter with a ftraight metal rule, and the back of the mould will be fmooth and regular. The mould is next to be feparated from the page, and to be dried in an oven.

In cafting the plates, the dried mould is to be laid in a pan about two inches deep, with the face upwards, and a fmall moveable fcrew is to be placed at each fide or end of the pan to furnifh a prefs on the frame which contains the mould, and prevent the rifing up, and the metal is applied over the mould in the pan, and carried to the oven, in which it fhould remain from one to two hours, to acquire an equal degree of heat; for on the principle of equal temperature between the metal and moulds, the fuccefs of the operation wholly depends. And unlefs the oven be kept fufficiently hot to raife the temperature of the moulds to that of the melted metal, the experiment cannot fucceed.

Such is the finenefs of the compofition of the moulds, and fuch the accuracy of the procefs, that plates may be caft from the fineft engravings as perfect as the copper-plate itfelf, and might be worked in the fame manner, could it be cleaned after each operation with the fame facility, and if the metal did not difcolour the paper. Wood-cuts, ornaments, &c. are caft in the fame manner, perfectly correct. The art has alfo been applied to the printing of mufic.

When the pages are returned from the foundery, they require to be thoroughly cleaned; for if the oil be fuffered to remain on the letter, it will not only be difagreeable to diftribute and compofe, but the dirt which adheres to it will fpoil the next mould to be made from it; hence it is neceffary that the letter be thoroughly cleaned with boiling water and a brufh, which increafes the expences attached to this art very confiderably.

After a plate has been caft, a few fmall imperfections will frequently be difcovered; fuch as that the eye of the *e*, or fimilar letters, may have been full of dirt when the mould has been taken; of courfe the plate will exhibit thofe parts filled with metal, which now require to be corrected. A workman, called a *picker*, takes the plate, and after clearing it of all fuperfluous metal, pulls a proof, marks the defects, and proceeds to make the requifite alterations in a manner that will now be eafily underftood. If, in the courfe of the work, any damage be done to the plate, or any letter or word be broken, the picker cuts it out, and inferts in its place a moveable type. This is very practicable, and only requires the letters to be cut fquare, fo that the type may exactly fit the place. In this way a letter, a word, or even a line, may be taken out and corrected without injuring the plate. The plate is now ready for the prefs, and may be laid on blocks, and faftened down with a flip of brafs and a fcrew.

With refpect to the advantages to be obtained by the ftereotype over the common mode of printing, it may be obferved, that the calculations of Mr. Wilfon, already referred to, of an actual faving of 30 or 40 *per cent.* feem to have been much over-rated. Mr. Brightly, who practifed the method of ftereotype for fome years, having made feveral eftimates, and being himfelf a printer as well as publifher, could have no inducement to give an exaggerated ftatement on either fide of the queftion, feems to doubt if there be any faving whatever by the new procefs. Among others, he has given the eftimate of the expences of a work printed in both ways, equal to twenty fheets octavo, of which 1000 copies are fold annually. Here he affumes, that in the common mode, the 4000 copies muft be worked at once, but according to the ftereotype plan, 500 copies are to be worked every fix months, to fave the intereft of money. Suppofing the paper in both cafes to be thirty fhillings *per* ream, the calculation is as follows:

Price of Common Printing.

	£	s.	d.
Compofition	14	0	0
Reading	3	10	0
Prefs-work	24	0	0
	41	10	0
Other expences and profits	20	15	0
	62	5	0
One hundred and fixty reams of paper	240	0	0
	302	5	0
Intereft of money for the firft half year	7	11	0
Ditto for the fecond half year - -	6	12	1½
Ditto for the third half year - -	5	13	3
Ditto for the fourth half year - -	4	14	4½
Ditto for the fifth half year - -	3	15	6
Ditto for the fixth half year - -	2	16	7½
Ditto for the feventh half year - -	1	17	9
Ditto for the eighth half year - -	0	18	10½
	336	4	6

Price of Stereotype.

Compofition, allowing one-fifth extra (fee above)	16	16	0
Reading - - - - -	3	10	0
Prefs-work for five hundred copies, fourth extra	3	15	0
	24	1	0
Other expences and profits	12	1	6
	36	2	6
Cafting plates -	50	0	0
	86	2	6
Twenty reams of paper	30	0	0
	116	2	6
Intereft for fix months	2	18	6
Carry over	119	1	0

	£	s.	d.
Brought forward - - -	119	1	0
Coſt of the firſt five hundred, ſecond, and of each ſubſequent five hundred, will be 38*l.* 5*s.* 3*d.* - - -	267	16	9
	386	17	9
Common printing - - -	336	4	6
Balance againſt ſtereotype, after four years	50	13	3
The next edition of four thouſand copies by common printing will coſt as before	336	4	6
Ditto on ſtereotype eight times 38*l.* 5*s.* 3*d.*	306		
Balance in favour of ſtereotype in the ſecond edition - - -	30		

Hence it appears, that it will require more than ten years to clear the expence of the plates only, and after that it will yield a profit of 30*l.* 2*s.* 6*d.* on every ſubſequent edition of 4000 copies.

From the foregoing eſtimate, and ſeveral others given by the ſame author, which are not more favourable to the new mode of printing, other advantages muſt be looked for than thoſe which reſult from pecuniary ſavings; but new diſcoveries may render the proceſs more economical than it is at preſent: thus, if the pages could be caſt ſo true, that they might go to preſs, and be worked with the ſame eaſe and expence as moveable types; and if a ſubſtitute could be found for oiling and bruſhing the pages ſo as not to wear the type, or increaſe the labour of the compoſitor, more decided advantages would reſult from the introduction of ſtereotype: ſuch as the following.

1ſt. On books publiſhed in parts or numbers. Purchaſers frequently take in the early parts and leave off, by which the ſets become broken and uneven, and a great loſs is incurred by the waſte of paper. This might be prevented by ſtereotype, which ſo remarkably facilitates the perfecting any parts or numbers that are found deficient.

2dly. On new books of doubtful ſale. The plan of caſting plates would not involve an expence of more than ſixpence for an octavo page, beſides the metal, which will ſtill retain its value. So that a hundred, or a leſs number of copies, might be ſtruck off to aſcertain the opinion of the public. If it did not ſell, the loſs on a work of 20 ſheets would not be more than about 8*l.*, beſides the compoſition; but if 500, or 750 copies were printed in the common way, and not ſold, the loſs would be from 30*l.* to 40*l.*

3dly. The principal advantage is unqueſtionably on ſtock books, whether bibles, prayer-books, or ſchool-books, particularly works of arithmetic, and other branches of mathematics. Theſe, by means of the ſtereotype, may be brought to perfect accuracy; and having once attained to that ſtandard, may be kept ſo without the poſſibility of deviation: for this excellence, the public would not grudge even an extra price.

Still

STILL, the name of an apparatus ufed in diftillation. See DISTILLATION and LABORATORY. See alfo ALEMBIC, RETORT, WORM, &c.

Dr. Lewis has contrived a ftill, adapted to his portable furnaces, which is fufficient for the purpofes of an experimental laboratory. The body of the ftill is a wide copper pan; and, for diftillation in a water-bath, another veffel of the fame figure is received into it almoft to the top, the fpace between them being nearly filled with water. Both thefe veffels are of the fame width at the mouth, and either may be ufed as a ftill equally with the other: either of them ferves alfo, on other occafions, as an evaporating pan, a boiler for experiments in dyeing, and other like purpofes.

All the parts are made of thin copper plate, and well tinned on the infide with pure tin. In confequence of their

thinneſs, they admit of ſome alteration of their figure about the edges, ſo that though they ſhould not be perfectly round, they are readily accommodated to one another, and fit cloſe: the juncture is eaſily made perfectly tight, by applying round it narrow ſlips of moiſtened bladder, which are more convenient than luting, as being readily ſtripped off when the operation is finiſhed. A ſhort pewter pipe, with a pewter ſtopper fitted to it, for returning the diſtilled liquor, or pouring freſh liquor occaſionally into the ſtill, without the trouble of unluting and ſeparating the veſſels, is ſoldered into the top of the head, which, in theſe kinds of inſtruments, is the moſt convenient place for it. For ſeparating, by diſtillation, ſpirituous from watery liquors, or the rectification of ſpirit of wine, the head is raiſed, by inſerting between it and the breaſt, a thin copper pipe about two feet long. A worm and refrigeratory are neceſſary, as for the common ſtill; and a glaſs head is requiſite for ſome uſes, particularly for the diſtillation of vinegar, and ſuch other liquors as would corrode a copper one, and impregnate themſelves with the metal; in which caſe, the uſe of the metalline worm alſo is to be avoided, and the glaſs or ſtone-ware receiver joined to the pipe of the head. Lewis's Com. of Arts, p. 9, 10.

STILL-*Bottoms*, in the *Diſtillery*, a name given by the traders to what remains in the ſtill, after the working of the waſh into low wines.

Theſe bottoms are procured in the greateſt quantity from the malt waſh, and are of ſo much value to the diſtiller in the fattening of hogs, &c. that he often finds them one of the moſt valuable articles of the buſineſs. They might alſo be put to other uſes, ſuch as the affording of a large proportion of an acid ſpirit, an oil, a fuel, and a fixed ſalt; and with ſome addreſs, and good management, a vinegar and a tartar. Another very advantageous uſe of them, is the adding of them to the next brewing of the malt for more ſpirit: the increaſe of the produce from this is more than could eaſily be conceived. It alſo more readily diſpoſes the new waſh to ferment, and gives the ſpirit a vinoſity that it cannot have without it; the proportion, in this caſe, can never exceed that of a fifth or ſixth part of the whole quantity of the liquor employed. The liquor left behind in the ſtill, after the rectifying of the low wines into proof-ſpirit, is alſo called by ſome by the name of ſtill-bottoms; but this is little more than mere phlegm, or water impregnated with a few acid, and ſome oily parts, not worth ſeparating, unleſs for curioſity. The liquor left in the ſtill, after the rectifying of the proof-ſpirit into alcohol, is alſo of the ſame kind.

The bottoms of molaſſes ſpirits ſeem calculated for many uſes. It is very probable that the vinegar-makers would find their account in trying them, and the ſtrong and laſting yellow colour with which they tinge the hands may recommend them to the dyers. A ſmall proportion of them, added to the new treacle to be fermented, greatly promotes the operation, and increaſes the quantity of ſpirit.

The bottoms of the wine ſpirit, that is, the remainder after diſtilling the ſpirituous part from damaged wines, or wine-lees, may be brought to afford Mr. Boyle's acid ſpirit of wine, and that ſubſtance, called by Becher the *media ſubſtantia vini*. A parcel of tartar may alſo be procured in very great perfection; and the laſt remainder may be converted into excellent and genuine ſalt of tartar. The liquor may otherwiſe be ſerviceable in making vinegar and white lead. Shaw's Eſſay on Diſtillery.

STILL-*Houſe*. The Dutch have much the advantage of us in the ſtructure of their ſtill-houſes, and have every thing in great readineſs and neatneſs. The general rules in building theſe houſes ſhould be theſe:

The firſt caution is to lay the floor aſlope, not flat, where any wet work is to be performed: it ſhould alſo be well flagged with broad ſtones, ſo that no wet be detained in the crevices, but all may run off, and be let out at the drains made at the bottom and ſides.

The ſtills ſhould be placed abreaſt on that ſide of the ſtill-houſe to which the floor has its current. The largeſt ſtills in Holland, for their greateſt works, are never of that monſtrous ſize which are conſtructed in England, but much more manageable and convenient, as ſeldom containing more than ſix or eight hogſheads; and with ſuch ſtills a ſingle hand will perform more buſineſs than with one of a much larger ſize. Fronting the ſtills, and adjoining to the back wall, ſhould be a ſtage for holding the fermenting backs, and theſe being placed at a proper height, may empty themſelves, by means of a cock and a canal, into the ſtills, which are thus charged with very little trouble.

Near this ſet of fermenting backs ſhould be placed a pump or two, that may readily ſupply them with water by means of a trunk or canal, leading to each back. Under the pavement adjoining to the ſtills ſhould be a kind of cellar, wherein to lodge the receivers, each of which ſhould be furniſhed with its pump, to raiſe the low wines into the ſtill for rectification; and through this cellar the refuſe waſh, or ſtill-bottoms, ſhould be diſcharged by means of a hoſe, or other contrivance. Theſe are the principal things to be regarded in the erecting of a ſtill-houſe for the original production of ſpirits; and if theſe rules are well obſerved, malt-ſpirit will be made with little more trouble than molaſſes; for by this means the buſineſs of brewing and cooling the waſh, which, according to the method generally practiſed in England, takes up ſo much time and trouble, is entirely ſaved, fermentation is carried on to a much greater advantage, and the quantity of ſpirit increaſed. Shaw's Eſſay on Diſtillery.

Stocking-frame

STOCKING-*Frame*, a moſt ingenious machine for weaving or knitting of ſtockings. To comprehend the action of this machine, which is extremely complicated, it is firſt neceſſary to have a perfect idea of the nature of the fabric which is produced by it: this is totally diſtinct from cloth woven by a loom, as the ſlighteſt inſpection will ſhew; for inſtead of having two diſtinct ſyſtems of threads, like the warp and the weft, which are woven together, by croſſing each other at right angles, the whole piece is compoſed of a ſingle thread, united or looped together in a peculiar manner, which is called ſtocking-ſtitch, and ſometimes chain-work.

This is beſt explained by the view in *fig.* 1. *Plate Stocking-frame.* A ſingle thread is formed into a number of loops or waves, by arranging it over a number of parallel needles, as ſhewn at R: theſe are retained or kept in the form of loops or waves, by being drawn or looped through ſimilar loops or waves formed by the thread of the preceding courſe of the work, S. The fabric thus formed by the union of a number of loops is eaſily unravelled, becauſe the ſtability of the whole piece depends upon the ultimate faſtening of the firſt end of the thread; and if this is undone, the loops formed by that end will open, and releaſe the ſubſequent loops one at a time, until the whole is unravelled, and drawn out into the ſingle thread from which it was made. In the ſame manner, if the thread in a ſtocking piece fails or breaks at any part, or drops a ſtitch, as it is called, it immediately produces a hole, and the extenſion of the hole can only be prevented by faſtening the end. It ſhould be obſerved, that there are many different fabrics of ſtocking-ſtitch for various kinds of ornamental hoſiery, and as each requires a different kind of frame or machine to produce it, we ſhould greatly exceed our limits to enter into a detailed deſcription of them all. That ſpecies which we have repreſented in *fig.* 1. is the common ſtocking-ſtitch uſed for plain hoſiery, and is formed by the machine called the common ſtocking-frame, which is the ground-work of all the others.

Fig. 2. is a perſpective view of a common ſtocking-frame, exhibiting as many of its parts as can be ſeen in a general view. The baſis is a wooden frame, conſiſting of four pillars N, and various croſs-pieces, called rafters: the two uppermoſt, M, are called caps: upon the top of theſe the ſmall parts of the machine are ſituated, being ſuſtained in a frame of wrought iron. The pieces which compoſe the iron frame are two ſole-bars *w*, which are ſcrewed down upon the wooden caps M, and at the ends have joints, *g*, to ſupport the preſſer-bows G, G, of which we ſhall ſoon have occaſion to ſpeak. At the back are two vertical ſtandards, V, called the back ſtandards, which ſupport the axis T. Theſe ſtandards are united by back croſs-bars, which are clearly ſeen in the figure near V. There are likewiſe two front ſtandards W, erected from the ſole-bars *w*, *w*.

To give motion to this machine, the workman ſeats himſelf before it, upon a board or ſeat A, and puts the different parts of the machine in motion by his hands and feet: he applies his feet upon two treadles B, C, which have cords, *b*, *c*, aſcending from them, and paſſing in oppoſite directions round a barrel or wheel, upon the axis of which is a large wheel, D, called the ſlur-wheel. By alternately preſſing down one treadle, and allowing the other to riſe, he can turn this wheel round in either direction at pleaſure. The object of this movement will be deſcribed hereafter. There is likewiſe a third treadle, E, upon which he preſſes his foot, when he wiſhes to bring down what is called the preſſer-bar, marked F, the uſe of which will be afterwards explained. This bar is attached to two arms or levers G, which are moveable round the fixed centre pins or joints *g*. The ends of the levers are of a curved form; hence the pieces G are called

the preſſer-bows. The connection with the treadle E is by a ſtring or wire *e*, which aſcends behind the machine, and is attached to the croſs-bar H, which is extended from one of the preſſer-bows to the other, and is cranked down, to avoid ſuch parts of the machine as it would otherwiſe intercept in its motion. The return of the preſſer and middle treadle, E, is produced by the re-action of the wooden ſpring I, which draws it up with two ſtrings; but in ſome frames a counter-weight is uſed inſtead of the ſpring.

The weaver produces all the other movements by his hands: for this purpoſe, he applies them to the ends K, K, of the hand-bar, and he can then very conveniently preſs his thumbs upon the thumb-plates L, L. By drawing forward or lifting up the hand-bar K, and at the ſame time preſſing upon the thumb-plates L, or relieving them, he gives the requiſite motions to what is called the frame of ſinkers, or ſimply the frame, becauſe it contains the principal works of the machine. The thread of which the ſtocking is to be made is kept upon a bobbin M, ſtuck upon a pin in the front upright, N, of the frame, and the thread from this is carried upon the needles; and when it is woven into the ſtocking piece by the action of the needles and ſinkers, the piece hangs down at S, and is received upon a ſmall roller fixed in an iron frame *p*, called the web, which is made ſufficiently heavy to ſtretch the piece to a moderate tenſion.

As an introduction to a deſcription of the whole machine, it will be proper to give the reader an idea of thoſe parts which operate upon the thread, and of the motions which are given to them to produce the loops or meſhes. Theſe parts are the needles, the frame of ſinkers, and the preſſer-bar: the needles are ſtationary, the reſt moveable.

Fig. 1. repreſents what are called the needles: theſe are made of iron-wire, of the ſhape repreſented, and are hooked or barbed at the ends, the returned points of the hooks or barbs being made very delicate. There is a ſmall cavity or groove punched or ſunk in the ſtem of the needle, immediately beneath the barb, of ſufficient depth to receive the point, when an adequate preſſure is applied upon the hook to bend the barb down. The barb then becomes a cloſed eye; and if a thread is looped over the wire or ſtem of the needle, and drawn forwards while the barb is thus cloſed, it will draw over the barb of the needle, and come off at the end of it: but if the thread is drawn forwards whilſt the barb is open, it will be caught under the hook, and be thus detained, as ſhewn at R. This circumſtance muſt be particularly attended to, as the principal action of the machine depends upon it. The depreſſion of the barbs of the needles is produced by the edge of the preſſer-bar F, which is extended horizontally over the whole length of the needles, and actuated by preſſing the foot on the middle treadle, as before explained.

Between every two adjacent needles, 1, 1, a thin plate of ſteel, 2, 3, is placed: theſe plates are called ſinkers; they are formed to a particular ſhape (as ſhewn in *fig.* 4.), and are capable of being elevated or depreſſed, and alſo of being drawn backwards or forwards between the needles. Theſe motions are given by the hands of the weaver, as the hand-bar K, which he holds, is part of the frame containing the jacks and ſinkers. The ſinker-frame conſiſts of the hand-bar K K (*fig.* 2 or 4.), extending acroſs it at the bottom; the hanging cheeks O, O, which form the upright ſides of the frame; and the upper bar P, which is called the ſinker-bar, becauſe the ſinkers are fixed to it, being united ſeveral together in pieces of lead each an inch wide, which are caſt round the ends of the ſinkers, and faſtened by ſcrews to the bar P.

To allow the frame of ſinkers to have the motions of which we have ſpoken, it is ſuſpended by joints at the top of the hanging-cheeks, called the top joints: theſe joints are formed at the ends of the top arms, Q, Q, which are two horizontal levers fixed to an axis T, called the ſpindle-bar: the extremities of this turn on pivots, ſupported by the upper ends of iron uprights V, called the back ſtandards. By the motion of the ſpindle-bar upon its centres, the frame of ſinkers can riſe and fall, and the quantity of this motion is limited by ſtop-ſcrews applied to the vertical ſtandards W. To draw the ſinkers forward between the needles, the ſinker-frame can be inclined upon the top joints of the hanging-cheeks, by drawing forwards the hand-bar K. From the middle of the ſpindle-bar, T, a ſhort lever projects, which is borne upwards by a ſpring, Y, called the main-ſpring: this is ſupported by a piece which projects from the fixed croſs-bar of the frame, and is of ſufficient force to bear the frame of ſinkers upward, and give the top arms, Q, Q, a tendency to reſt always againſt the upper ſtop-ſcrews, X, of the ſtandards W.

The hooked part or nips *f* (*fig.* 4.) of the ſinkers, are for the purpoſe of forming loops in the thread between the needles. To effect this, the nips, *f*, of the jacks and ſinkers are raiſed above the level of the needles, as in *fig.* 4, and the thread is extended acroſs all the needles, immediately beneath the nips. If then the jacks and ſinkers are all preſſed down between the needles, it is evident that the nips of the ſinkers muſt carry the thread down before them, and form it into loops hanging down between each needle, as ſhewn at X. This, then, is the principal office of the ſinkers: but to perform the operation of ſinking in the manner now deſcribed, by depreſſing the whole number at once, would not be practicable; becauſe, as a greater length of thread is required when it is depreſſed into loops, than when it lies ſtraight acroſs the needles, it would require to draw the thread all at once from the bobbin M (*fig.* 2.), in ſufficient quantity to make up the difference; to do which, the thread muſt ſlide or draw beneath between the nips and the needles, which it could not do, on account of the friction.

The contrivance to render this depreſſion or looping down of the thread between each needle practicable is very ingenious. The row of ſinkers ſhewn in *fig* 4. is compoſed of two kinds, called jack-ſinkers and lead-ſinkers, which are very different in their movements, although we have hitherto ſpoken of them as one. The lead-ſinkers are all thoſe of which we have ſpoken as being faſtened to one bar P, called the ſinker-bar, which is part of the ſinker-frame, and which the workman moves by his hands: on this account, the lead-ſinkers all move together; they are one half of the whole number, and are diſpoſed between every other needle, ſo that the ſpace between each lead-ſinker has two needles in it. The jack-ſinkers are made of the ſame form as the lead-ſinkers, one being placed between each of the two needles contained between every lead-ſinker; therefore the lead-ſinkers and jack-ſinkers are diſpoſed alternately to form a row, and a needle is placed in every ſpace in the whole row. Each jack-ſinker is ſupported by a ſmall lever, *b i*, (*fig.* 3.) called a jack, freely movable on a centre-pin: the oppoſite end *i*, or tail of each jack, is preſſed by a ſpring *k*, which has a notch or indentation at a particular place; and when the jack-ſinker is elevated, ſo that its nip, *f*, is above the level of the needles 1, ready to receive the thread, the end of the tail, *i*, is received in the notch of the ſpring *k*, which retains it in that poſition; but at the ſame time a ſlight force applied beneath the tail, *i*, of the jack to lift it up will depreſs the nip, *f*, of the jack-ſinker, 3, between the needles. It is to be underſtood, that all the jacks, *i b*, are arranged in a row, and move upon one wire, which is a common centre of

motion; but the motion is given to them one at a time, beginning at one end of the row, and proceeding one by one to the other. To effect this, a straight iron bar, or ruler *l*, called the slur-bar, is extended beneath all the jacks, and upon this a piece of metal, *m*, called the slur, travels, with rollers to reduce the friction: it is drawn by a line extended from each side, and conducted over a pulley *n*, at each end of the bar *l*, to be carried round the slur-wheel D, *fig.* 2. We have before explained how an alternate motion is given to this wheel, by the action of the two feet upon the two treadles B, C: it is plain by this connection, that the slur, *m*, can be made to travel from one end of the slur-bar, *l*, to the other, and in so doing, that it will elevate the tails, *i*, of all the jacks, *i*, *h*, beneath which it passes, and produce a corresponding depression of the jack-sinkers, 3, between the needles. After the slur has passed, the jacks retain the position given to them by the pressure of the springs *k*.

The operation of sinking or forming the loops between the needles is thus conducted: the nips of all the sinkers are raised above the needles, as in *fig.* 4; the thread is then extended lightly across the stems of the needles, beneath the nips *f*. By pressing on one of the treadles, B or C, the slur-wheel D is made to turn round, and this, by the slur-line, draws the slur, *m*, from one end of the slur-bar, *l*, to the other. In its passage it encounters the tails, *i*, of the jack, and lifts them up one by one, which at the same time depresses the correspording jack-sinker 3; and its nip, *f*, sinks the thread between the needles, and forms a loop. As these loops are formed successively, the thread draws easily beneath the nip to produce each single loop, and the workman allows the threads to draw off from the bobbin, M, through his fingers, as fast as it is required. When all the jack-sinkers are depressed, a loop of the thread will be formed between every other pair of needles. The workman then depresses the lead-sinkers, 4, by pulling down the hand-bar K, and their nips carry down the thread between the remaining needles in loops, in the intermediate spaces between the former loops: in doing this, he causes the jack-sinkers, 4, to rise up, as much as he depresses the lead-sinkers 3; because it should have been mentioned before, that the first loops formed by the jack-sinkers were double the depth intended, although only half the number: by this means they contained the proper quantity of thread to form the whole number of loops; *viz.* one between every two adjacent needles.

The jack-sinkers are caused to rise up by means of the locker-bar, *p*, extending over all their tails *i*. Each end of this bar is screwed to a lever, *g*, called a locker, which moves upon the same centre as the jacks, and the front ends of these levers are made with inclined ends, so as to be lifted up by wedges fixed at the back of the thumb-plates, L, which move on joints fixed to the sinker-bar, and hang down in a convenient situation to be acted upon by the thumbs of each hand, when holding the ends of the hand-bar K. The weaver, therefore, presses back the two thumb-plates L, at the same time that he depresses the hand-bar, K, of the frame containing the lead-sinkers; by which means he produces the ascent of the jack-sinkers, in an equal degree to the descent of the lead-sinkers, until the nips of the two arrange exactly in one line, which position is determined by proper stops attached to the sinker-frame. By this means, a complete row of loops is formed, one loop between each needle.

These loops are now to be carried backwards upon the needles, into the position of S, *fig.* 1, so as to occupy the arch or opening, *s*, of the sinkers, which open part is made purposely to admit the loops last made to remain upon the stems of the needles, quite detached from the action of the sinkers, which are at liberty to form a new course of loops by the nips, *f*, of their points *t*.

If we suppose the frame has been before at work, the loops last formed, which hang upon the stems of the needles, will not be a single thread, but the loops at the upper part of the work S, *fig.* 1: it is only when the frame first begins to work that the loops will be a detached thread, as we have just described.

But it remains to shew how the loops are put back upon the needles: this is done by merely lifting up the hand-bar K, till the points, *t*, of the sinkers rise above the needles: the hand-bar is then drawn forwards a little, to advance the sinkers so much, that the points *t*, which were behind the loops of thread upon the needles, will now come before them, and then the hands are depressed, to insert the points, *t*, between the needles again before the threads; and by pushing back the hand-bar, the points, *t*, carry back the work upon the stems of the needles, so that it will be situated in the arch, or opening, *s*, of the sinkers.

When the sinkers advance or recede, they must all move together both the lead-sinkers and jack-sinkers, as if they were one. It is clear that there is no impediment to the moving forwards of the lead-sinkers, because they are at liberty to incline or swing forwards upon the joints at the tops of the hanging-cheeks, O, O, which suspend the frame containing them: but for the jack-sinkers to advance at the same time, it is necessary to bring forward the jacks, and their centre of motion, together with the springs and slur-bar. To admit of this motion, all those parts are framed upon a strong bar called the camel; and upon this is placed four wheels, which run upon the sole-bars, so as to become a carriage. To communicate motion to this carriage, a link is jointed to a piece at each end, marked *r*, *fig.* 2 or 4, which is screwed to the sinker-bar P, just within the thumb-plates L. These links are jointed at the other ends to the common centre of motion of the jacks. The joints of the pieces, *r*, are so adjusted, that they will exactly line with the joints which unite the jacks and jack-sinkers together; and the links are the same length between the centres as the jacks, for which reason they are called half-jacks.

By means of this connection, the carriage, with all its appendages, *viz.* the jacks, with their springs and the slur-bar, are drawn forwards at the same time that the sinker-frame is drawn forwards, by pulling the hand-bar K K; or, by a contrary movement, the loops of threads which were last formed upon the needles, will be carried back from the hooks or beards of the needles upon their stems, as shewn at S, *fig.* 1, so as to be in the arch, *s*, of the sinkers, as before described.

The first row of loops being thus disposed of, the frame of sinkers is restored to its former position, and a second row is formed upon the stems of the needles by a repetition of the same process, *viz.* extending the thread across the needles beneath the nips, *f*, of the sinkers; moving the slur by the two outside treadles B, C, which depresses all the jack-sinkers, and makes a loop of double depth between every other pair of needles: this is called drawing the jacks: next pressing on the thumb-plates L, and depressing the hand-bar, K, at the same time, which elevates the jack-sinkers, and depresses the lead-sinkers by one movement, and produces a loop of thread between every two adjacent needles. Another complete row of loops is now formed upon the stems of the needles; and this row is to be brought forwards, so as to be under the beards or hooks of the needles, in the manner shewn by R, *fig.* 1. This is produced by simply drawing forwards the hand-bar K,

which advances all the finkers together, and their points, *t*, push forwards the thread till it comes into the beards, and these prevent it from coming off the needles.

The next operation is lifting up the hand-bar and frame of finkers as much as will raise their points, *t*, quite clear up above the needles between which they were situated, and applying the foot on the upper treadle E, to bring down the pressing-bar, F, upon the beards of the needles, to close them up, and while so closed, they hold the loops of thread at R, as if they were looped through the eyes of as many needles. The upper loops of the works which are at S, *fig.* 1, upon the stems of the needles, in the arch, *s*, of the finkers, are next brought forward upon the needles, by drawing forwards the frame of finkers; but in advancing these loops, draw over the closed beards of the needles, and consequently over the last-formed hoops, which remain under the beards, in the position shewn at R, *fig.* 1; or, in other words, the loops last formed, and resting under the beards at R, *fig.* 1, are drawn through the loops of the upper or last course of the finished work which remained upon the stems of the needles, as represented at S. By this means, the loops of what was the upper or last course of the finished work, become secured from opening or unravelling, and the loops under the beards now become the last or upper course of the work, and are preserved from unravelling by the needles, one of which passes through each loop; and these loops will not be drawn off from the needles until there is another row of loops prepared, and reserved under the beards of the needles, ready to be drawn through them. When the piece of work is finished, and taken off from the frame, the last made row of loops must be secured by running a thread through them, or other means, or they would draw through the preceding loops, and release them, which in like manner would release their predecessors, and so the whole piece would unravel.

The motion of the frame of finkers, which produces the advance of the finkers towards the points of the needles, or their recession towards the stem, takes place upon the centres, called the top joints *o o*, and the wheels of the carriage, as before mentioned. The quantity of motion is limited by a piece, *fig.* 7, called the arch, which is fixed fast against the inside of the wood-frame N, *fig.* 2: a part of the hanging-cheeks O, O, of the frame of finkers descends with a projecting part to act round this arch, which, at the same time that it limits the quantity of motion, prevents the motion being made, except in a proper succession, to produce the effects before described. Thus, when the hook is beneath the arch, the points, *t*, of the finkers will be beneath the level of the needles, and then the frame of finkers cannot be raised up without first moving the lower part of the frame either forwards or backwards. In the same manner, when the hook is above the arch, the finkers cannot be depressed till they are moved. When the thread is first extended across the needles, in order to be sunk into loops, the frame is said to be over the arch, that is, the hook is at the back, or on the farther side of the arch, and by applying thereto, the finkers are guided in their finking, that is, when they descend, they depress the thread to form the loop. When this finking has taken place, the finker-frame will be at its lowest position, and the top arms, Q, will rest upon the lower stop-screw of the standards W. When the finkers are brought forwards, to draw the loops from the stems of the needles into their beards or points, the hook of the frame moves along the under side of the arch, and this prevents the points lifting up, while the lower stop prevents them from finking down: but when the finkers are brought sufficiently forwards, the frame is lifted or thrown up by the main-spring, the hook following the curvature of the arch, until the points are completely above the needles, or the frame has reached the upper stop. The finkers are then brought forwards upon their centre of motion, while the presser is drawn down to close the beards of the needles and draw the loops over them; in doing which, the hook quits the arch, and the frame comes forwards without any guide, the same being unnecessary, because the elevation of the finkers is determined by the upper stop, against which the frame rises by the action of its main-spring; and the proper degree for the advance of the finkers is determined by the drawing forwards of the frame with sufficient force to draw the loops of the work tight: this force the workman must regulate by habit, so as make his work close.

In returning the frame of finkers, in order to put back the work upon the stems of the needles, so as to be out of the way while a new row of loops is made, the hook, 9, must be carried back beneath the arch, which will keep down the points of the finkers, so as to prevent them from rising above the needles, as they would then quit the work they are intended to drive back upon the needles.

By the operation which we have described, one course of the work is formed; but, to render it more clear, we will continue the description, in a few words, of the working of another course. Preparatory to working it, the loops of the last course of the work, and by which the work is suspended from the needles, must be pushed back upon the stems of the needles to the position S, *fig.* 1, so as to come into the arched or open part *s*, *fig.* 4, of the finkers: this is done by depressing the finkers low enough for their point, *t*, to enter between the needles, and then pushing back the hand-bar and frame of the finkers to carry back the work upon the stems of the needles. This is the situation in which we suppose the frame, when the operation commences; and the frame is over the arch.

The first movement is the gathering of thread. The thread laid over is lightly extended across the needles, beneath the nips, *f*, of the finkers; and by pressing the slur-treadle B C, the jack-finkers are depressed one by one, so as to form double loops. This is called drawing the jacks.

The second movement is finking. This is done by drawing down the hand-bar K, and bearing upon the thumb-plates, L, at the same time: the whole row of lead-finkers is thus depressed, whilst the jack-finkers rise, and the thread is carried down into a loop between every two needles.

The third movement is to bring the frame forwards under the arch. This is done by drawing the hand-bar forwards, and the row of loops just made is brought under the beards of the needles.

The fourth movement is to bring the work forwards from the stem of the needles. To do this, the finker-frame is lifted up, by elevating the hand-bar K, so that the point, *t*, of the finkers will be quite drawn out above the needles; and in this situation, the hand-bar and finker-frame being brought forwards, the breast or curved part of the arch, *s*, of the finker will bring forwards the piece of work which hangs upon the stems of the needles, by its loops last made.

The fifth movement is closing the work, or drawing the loops last made, through the finished loops of the work. The presser-treadle E, being borne upon at the same moment, will bring down the presser, and it will bear upon the beards, and close them, while the loops are drawn forwards; consequently the loops of the old work will be drawn over the beards, and quite off from the needles: this draws the loops thereof over the loops last made, which re-

main in the beards of the needles. To draw the work tight, the hand bar, K, is drawn forwards two or three times with a flight jerk, fo as to extend all the loops to their fulleft quantity, and make the loops of the work unite clofely.

The courfe is now finifhed; but as a preparation for making another courfe, the work muft be carried back upon the ftems of the needles into the fituation of S, *fig*. 1. This is the fixth and laft movement. To put back work, the frame is pulled down to bring the points of the finkers below the level of the needles; and in this pofition, by preffing back the hand-bar, and all the finkers together, the points, *t*, will enter between the ends of the needles, and carry back the loops of the work upon the ftems of the needles, where it will remain in the arches of the finkers, fo as to be detached from them, and out of the way, while a new fet of loops is formed by the nips of the points of the finkers; and then the loops of the old work are to be drawn over thofe laft made.

The movements are then repeated: 1ft, gathering the thread upon the needles, and depreffing it into large loops between every two needles, by the motion of the flur; 2d, finking, to make the loops between all the needles; 3d, bringing the thread under the beards of the needles; 4th, bringing the work forwards from the ftems of the needles towards the beards; 5th, clofing the beards by the preffure of the preffer-bar, and drawing the work over the beards; and, 6th, putting the work back on the needles, ready for working another courfe.

The operation of the machine proceeds in the manner defcribed; and as faft as the courfes are completed, the work defcends lower, and hangs down in a web from the needles. When the piece is of a confiderable length, it is rolled upon a roller, in an iron frame *p*, called the web, and the weight of the frame is fufficient to keep the piece to a proper tenfion. The roller in the web can be turned round occafionally to wind up the piece, and is retained by a ratchet-wheel and click.

Having given an idea of the manner of the operation of this curious machine, it only remains to explain the adjuftments with which it is provided, in order to make it work correctly.

The finenefs of the work depends on the number of loops which the thread will make in any given length, and this will be equal to the number of needles and finkers in the fame fpace. The number of needles in an inch is called the gauge of the frame, and they vary from 15 to 40, which latter are ufed for the fineft ftockings. The gauge of a frame cannot be altered when it is once made, and the work which it will produce muft always be of the fame degree of finenefs, although it may be made a little more denfe or more flight by drawing the loops very clofe, or by allowing a greater quantity of thread, and making the loops longer. This circumftance will evidently depend upon the depth to which the nips of the finkers defcend between the needles, when they carry down the thread into loops. To regulate this depth, the needle-bar, or that piece which fuftains the leads containing the row of needles, is made to rife or fall a flight quantity, by means of two long adjufting fcrews, the heads of which are made with notches, and fprings fall into them to keep the fcrews from turning back: thefe heads are called the ftar, and the notches nicks: one is marked 9, in *figs*. 2 and 3.

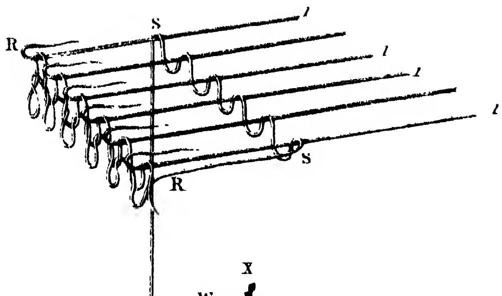
The motion allowed to the frame of finkers is limited, as before-mentioned, by ftops projecting from the two upright ftandards, W; and through thefe ftops, ftop-fcrews, *x*, are fitted, to regulate the degree of afcent and defcent. The main-fpring, *y*, is made of fufficient ftrength to lift the weight of the frame of finkers, and make them always rife up as high as the upper ftop-fcrews will permit.

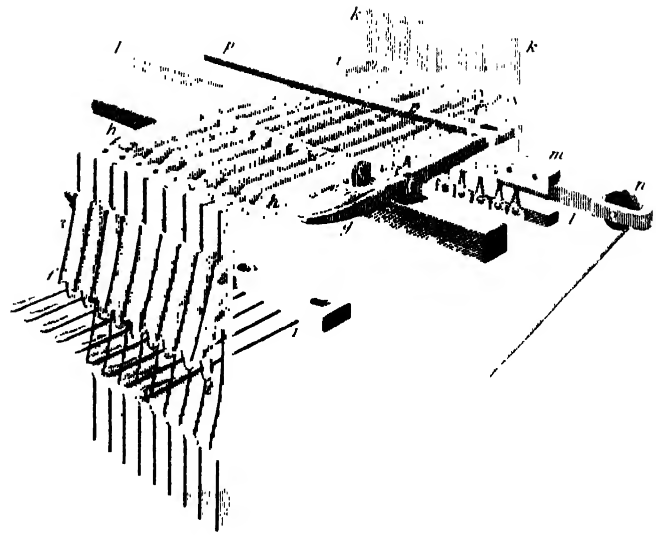
The manner of making different parts of the ftocking-frame is worthy of notice. The needles are made of iron-wire, of a proper degree of finenefs: it muft be of good quality, as that which is liable to fplit or fplinter, either in filing, punching, or bending, is totally unfit for the purpofe. The wire is cut to lengths, and annealed or foftened in a box of charcoal, in which they are heated to rednefs, and fuffered to cool gradually. The needles are next punched with the fmall cavity which is neceffary to receive the point of the beard: this is done by a fimple fcrew-prefs. The point of the needle is next formed by the file and burnifher, and the hooks are then bent to form the barb: next the needles are flattened, each with a blow of the hammer. To faften thefe needles together, and fix them in the machine, they are placed parallel to each other in a mould or frame, and tin or pewter poured into the mould, round the flattened ends of the ftems. The piece of lead or pewter is juft an inch in width, and the number of needles which it will contain, gives the denomination to the gauge of the frame. Thefe leads of needles are faftened to the needle-bar by a fcrew through each. The lead-finkers are made of fteel-plates, which are put together by cafting lead round them at the upper ends, in the fame manner as the needles. The rack or piece, which contains the centre of the jacks, is called the comb, becaufe it is compofed of a number of fmall plates, fixed into a bar by cafting them with lead or tin.

The ftocking-frame has undergone very few alterations fince its firft invention, a circumftance highly creditable to the genius of the inventor. A ftocking-frame for weaving the tartan plaid hofe which is worn in Scotland, is defcribed in the Society of Arts Tranfactions, vol. xxix. p. 84: it contains fome additions invented by Mr. John Robertfon.

STOCKING FRAME

Fig 1





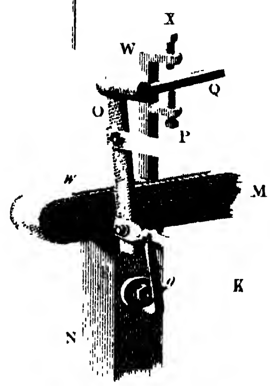


Fig 7

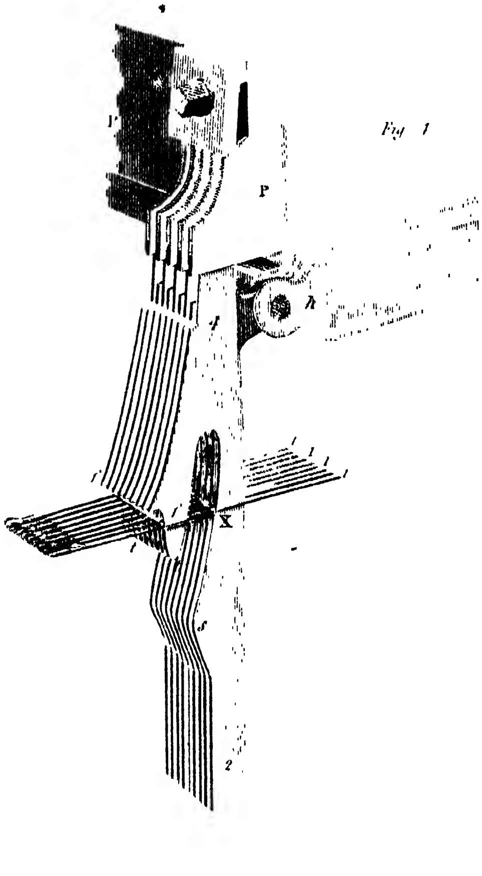
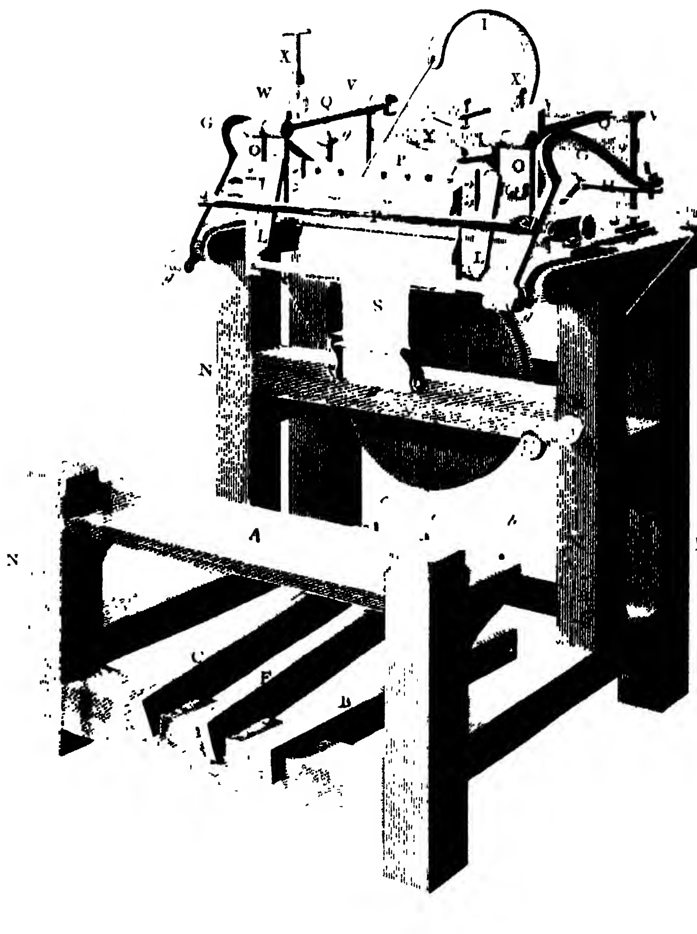


Fig 1

Fig 2.



Stove

STOVE, in *Building*, a hot-houſe or room. The term ſtove is alſo uſed more reſtrictedly for a place in which fire is made, and by means of which heat is communicated to a room or building. See CHIMNEY.

Stoves ſhould, in propriety, be diſtinguiſhed from fire-places, from the fire being incloſed within the ſtove, and giving out its heat through the ſubſtance of the materials of which the ſtove is compoſed, to the air in the apartment; and in many ſtoves there are ingenious contrivances, to make a great quantity of air paſs in contact with the heated ſurface of the ſtove, and be thus heated before paſſing off into the apartment. Fire-places, on the contrary, have the fire as open and as much expoſed as poſſible, conſiſtently with the carrying off of the ſmoke, in order that it may throw out radiant heat into the apartment. This diſtinction is not ſufficiently attended to in common language.

In modern fire-places, every care is taken that the air of the room may be heated; but it does not appear, from the conſtruction of their fire-hearths, that our forefathers had any idea of warming the air of a room to ſit in. All they propoſed was to have a place to make a fire in, by the radiating heat of which they could warm themſelves when cold.

The ancients are ſuppoſed to have uſed ſtoves, in which the fire was not ſeen; but on inquiring into the progreſs of the art of warming apartments economically, few traces remain of the manner in which the ancients warmed their habitations. It is imagined they lighted the fire in a large tube in the middle of a room, of which the roof was open, and that the other apartments were warmed by portable braziers. In Seneca's time, they began to conſtruct tubes in the walls, to convey the heat into the upper apartments; the fire-places being ſtill placed below. It appears, however, that this was the origin of flues for ſmoke, and even of ſtoves; the ſituation and proportions of which have ſucceſſively undergone an infinity of changes, according to the localities, the wants of the inhabitants, or the ſtyle of the decorations.

The ancients had the cuſtom of heating apartments by fires placed under arches or vaults; but this was confined to palaces, and other edifices, where magnificence was augmented by prodigality; and the veſtiges that have been diſcovered among ancient ruins, ſufficiently point out this as their deſtination. In digging, ſome years ago, for foundations in the city of Autun, one of theſe ovens was diſcovered under a moſaic pavement, with chimnies at each extremity.

The northern Chineſe have a method of warming their ground-floor, which reſembles the ancient plan juſt mentioned. The floors are made of tiles a foot ſquare, and two inches thick; their corners being ſupported by bricks ſet on end, that are a foot long, and four inches ſquare: the tiles, too, join into each other, by ridges and hollows along their ſides. This forms a hollow under the whole floor, which on one ſide of the houſe has an opening into the air, where a fire is made; and it has a funnel riſing from the other ſide to carry off the ſmoke. The fuel is a ſulphurous pit-coal, the ſmell of which in the room is thus avoided, while the floor, and of courſe the room, are well warmed. But as the under-ſide of the floor muſt grow foul with ſoot, (and a thick coat of ſoot prevents much of the direct application of the hot air to the tiles,) Dr. Franklin ſuggeſts that burning the ſmoke, by obliging it to deſcend through the red coals, would, in this conſtruction, be very advantageous; as more heat would be given by the flame than by the ſmoke, and the floor, thereby being kept free from ſoot, would be more heated with leſs fire. A different kind of ſtove uſed in China, and called *kang*, is briefly deſcribed under that article.

Francis Keſlar of Frankfort, whoſe work, entitled "Epargne-bois," &c. (the Wood-ſaver, &c.), appeared, in French, in 1619, is the oldeſt writer who deſerves to be quoted, as having propoſed any uſeful ideas on the ſubject of ſtoves. He formed eight chambers, one above another, through which the ſmoke was to paſs before it entered the chimney. He alſo brought air directly from without into the aſh-pan, to feed the fire; and there was another aperture to draw air from the apartment for the ſame purpoſe.

Savot, in his "Architecture Françaiſe des Batimens particuliers," *i. e.* Architecture of private Houſes, printed in 1625, gave ſome advice relative to the beſt method of conſtructing chimnies, but with ſcarcely any other object than to prevent their ſmoking.

M. Daleſme, in 1686, ſuggeſted the firſt idea of a ſtove without ſmoke, which he called *furnus acapnos*. Here the ſmoke is forced to deſcend into the fire-place, where it is conſumed. Dr. Franklin, who afterwards executed a very complete ſtove on that principle, ſtill ſpoke of it, in 1773, as a mere curioſity or philoſophical experiment, as it required too much attention to be managed by common ſervants.

This machine conſiſted of a tube of iron-plate, ſuch as is uſed for the flue of a German ſtove. This tube was bent at right angles, and the part which was horizontal was about two feet in length, and joined to the reſt of the tube, which aſcended vertically. At the oppoſite end of the horizontal tube the furnace was made: it conſiſted of a cylindrical tube of plate-iron erected upon the horizontal tube near the end, and provided with a grating, upon which the fuel was placed; and the grate prevented the fuel falling down into the horizontal tube. To light this ſtove, ſome clear burning charcoal was put into the large ſhort tube or furnace, and ſupported on the grate. As ſoon as the tubes grew warm, the air within them would aſcend in the perpendicular tube or chimney, and go out at the top of it: freſh air muſt enter into the horizontal tube through the furnace. In this courſe it muſt deſcend through the burning fuel, and becoming heated by the burning coals, through which it has paſſed, would riſe more forcibly in the longer tube, in proportion to its degree of heat, or rarefaction, and the length of that tube. Such a machine is a kind of inverted ſiphon; and as the greater weight of water in the longer leg of the common ſiphon, in deſcending, is accompanied by an aſcent of the ſame fluid in the ſhorter; ſo in this inverted ſiphon, the greater quantity of levity of air in the longer leg, in riſing, is accompanied by the deſcent of air in the ſhorter. The things to be burned being laid on the hot coals contained in the furnace, the ſmoke muſt deſcend through thoſe coals, and be converted into flame, which, after deſtroying the offenſive ſmell, comes out at the end of the longer tube, as mere heated tranſparent gas or vapour.

Whoever would repeat this experiment with ſucceſs, muſt take care that the part of the ſhort tube is quite full of burning coals, ſo that no part of the ſmoke may deſcend and paſs by them, without going through them, and being converted into flame; and that the longer tube is ſo heated, that the current of aſcending hot air will be eſtabliſhed in it, before the things to be burnt are laid on the coals; otherwiſe there will be diſappointment.

It does not appear, either in the Memoirs of the Academy of Sciences, or Philoſophical Tranſactions of the Engliſh Royal Society, that any improvement was ever made of this ingenious experiment, by applying it to uſeful purpoſes; but there is a German book, entitled "Vulcanus Famulans," by Joh. George Leutmann, P.D., printed at Wirtemburg in 1723, which deſcribes, among a great variety of other ſtoves for warming of rooms, one which ſeems to have been formed on the ſame principle. It was probably taken from the hint thereby given, though M. Daleſme's experiment is not mentioned; for the conſtruction is as nearly as poſſible the ſame, except in the proportion of the parts; the furnace being made in the form of a baſin or vaſe, having the grate in the bottom of it.

Gauger, author of "La Méchanique du Feu," &c. printed at Paris in 1709, was the perſon to whom we are indebted for the firſt and moſt complete ſyſtem of experiments on the circulation of heat, by means of air-holes affording warm air; as alſo the manner of making one fire warm ſeveral rooms, and to ſend off the heat in elliptic

curves. We there find a defcription of a chimney, with the back, the hearth, and the jambs, of hollow iron, to heat the air that is to enter the room. But it does not appear that this work produced much effect at the time: the moft important truths lie concealed in books, till fome preffing intereft awakens the attention of mankind to their utility.

Dr. Franklin, in 1745, publifhed an account of the new ftoves of Pennfylvania; the advantages of which he compares with thofe of the ftoves of Germany and Holland, and the chimney of Gauger. A defcription and drawing of this ftove are given in our article FIRE-*Place*.

In 1785, Dr. Franklin publifhed the defcription of another ftove, which has the flame reverfed; that is, it paffes downwards through the fuel. The appearance of this ftove is that of a vafe of caft-iron, with its pedeftal; and this is mounted upon the top or lid of an air-box, ftanding upon the hearth of the fire-place, and built clofe in a niche in the ftone-work: but the vafe being wholly detached from the back of the niche, has a very neat appearance. The top of the vafe turns back upon a hinge, fo as to open like a lid, to put in the fuel; and the opening is covered by a brafs frame, which allows the air to enter. The bottom of the vafe has in it an opening, of about two inches diameter, which leads through the ftem or foot of the vafe into a hollow iron box, forming the pedeftal. At the bottom of this pedeftal is a grating in the lid or top of the air-box, upon which the vafe ftands. The air-box is divided by four partitions, between which the fmoke paffes and repaffes horizontally in a waving direction, until it efcapes into the chimney. Thus the fmoke and flame, immediately after it has defcended through the grate in the top of the air-box, paffes backwards towards the chimney between the two middle partitions; but as it cannot enter into the chimney at that part, it turns round the ends of thofe partitions, and returns in two currents towards the front of the box; then returns again round the end of other partitions, and goes back into the chimney, which is behind, or rather at the fides of the niche in which the vafe ftands. The front plate of the air-box is made to flide in a groove, in two pieces, which meet together in the front like folding-doors; and thefe pieces being flided back, expofe the fpaces between the partitions, which, as before mentioned, act as winding flues for the fmoke to circulate in, and give out its heat through the metal of the air-box. In the fpace between the two middle partitions, and into which the fmoke firft defcends, a drawer is fitted to receive the afhes or cinders, which may fall through the grate in the top of the air-box; and it can be readily withdrawn, to clear it out.

There is likewife a fmall grate at the lower part of the vafe, upon which the fuel contained in the vafe will reft. When this fuel is lighted, the flame and fmoke will draw downward, and, defcending through the grate, will pafs through the hole in the bottom of the vafe into the hollow pedeftal, and through the grate in the top of the air-box: it then paffes horizontally in the fpace between the two middle partitions of the air-box, and proceeds in the fame direction towards the back of the chimney; there dividing, one part of it turns to the right, and paffes round the farther end of the middle partition; then coming forwards, it turns round the near end of the outfide partition; then moving backwards, it arrives at the opening into the bottom of one of the upright corner funnels behind the niche, through which it afcends into the chimney, thus heating that half of the box and that fide of the niche. The other part of the divided flame paffes to the left, round the far end of the middle partition, round the near end of the outfide partition, and fo into and up the other corner funnel; thus heating the other half of the box, and the other fide of the niche. The vafe itfelf, and the box, will alfo be very hot; and the air furrounding them being heated, and rifing, as it cannot get into the chimney, it fpreads in the room: colder air fucceeding, is warmed in its turn, rifes and fpreads, till by the continual circulation the whole is warmed.

If there is occafion to make the fire when the chimney does not draw, it muft not be begun in the vafe, but in one or more of the paffages of the lower air-box; firft withdrawing the fliding front of the air-box, and covering the mouth of the vafe. After the chimney has drawn fome time with the fire thus low, and begins to be a little warm, thofe paffages may be clofed, and another fire kindled in the hollow pedeftal, leaving its fliding fhutter a little open; and when it is found that the chimney, being warmed, draws forcibly, that paffage may be fhut, and the vafe opened, to make the fire there, as above directed. The chimney, well warmed by the firft day's fire, will continue to draw conftantly all winter, if the fire is made daily.

In the management of this ftove, there are certain precautions to be obferved, at firft with attention, till they become habitual. To avoid the inconvenience of fmoke, the grate muft be cleared before beginning to light a fire. If it is found clogged with cinders and afhes, the grate muft be lifted up with the tongs, to let them fall upon the grate in the top of the air-box: the afhes will go through it into the drawer, and the cinders may be raked off through a fliding door in the pedeftal, and returned into the vafe, when they are to be burnt. Care muft be taken that all the fliding-plates are in their places, and clofely fhut, that no air may enter the ftove but through the round opening at the top of the vafe; and to avoid the inconvenience of duft from the afhes, let the afh-drawer be taken out of the room to be emptied. The paffages fhould be cleaned or raked out, when the draught of the air is ftrong inwards; and the afhes muft be put carefully into the afh-box, whilft it remains in its place.

If it is required to prevent the fire burning in the abfence of the proprietor, it may be done by removing the brafs frame from the top of the vafe, and covering the paffage or opening into the top of the vafe with a round tin-plate, which will prevent the entry of more air than barely fufficient to keep a few of the coals alive. When the fire is wanted, though fome hours afterwards, by taking off the tin-plate, and admitting the air, the fire will foon be recovered.

The effect of this machine, well managed, is to burn not only the coals, but all the fmoke of them; fo that while the fire is burning, if the top of the chimney is obferved, no fmoke will be feen iffuing, nor any thing but clear warm air, which, as ufual, makes the bodies feen through it appear waving.

But it muft not be imagined from this, that it can be a cure for bad or fmoky chimnies, much lefs that, as it burns the fmoke, it may be ufed in a room that has no chimney. It is only by the help of a good chimney, and the higher the better, that it produces its effect at all; and though a flue of plate-iron fufficiently high might be raifed in a very lofty room, the management to prevent all difagreeable vapour would be too nice for common practice, and fmall errors would have unpleafing confequences.

It is certain that clean iron yields no offenfive fmell, when heated: whatever fmell of that kind is perceived where there are iron ftoves, proceeds, therefore, from fome foulnefs burning or fuming on their furface; they fhould, therefore, never be fpit upon, or greafed, nor fhould any

duſt be ſuffered to lie upon them. But as the greateſt care will not always prevent theſe things, it is well once a week to waſh the ſtove with ſoap-lees and a bruſh, rinſing it with clean water.

The advantages of this reverſed flame in ſtoves are very conſiderable. The chimney does not grow foul, nor ever need ſweeping; for as no ſmoke enters it, ſo no ſoot can form in it.

The air heated over common fires inſtantly quits the room, and goes up the chimney with the ſmoke; but, in the ſtove, it is obliged to deſcend in flame, and paſs through the long winding horizontal paſſages, communicating its heat to a body of iron-plate, which, having thus time to receive the heat, communicates the ſame to the air of the room, and thereby warms it to a greater degree.

The whole of the fuel is conſumed by being turned into flame, and the benefit of its heat is obtained; whereas, in common chimnies, a great part goes away in ſmoke, which may be ſeen as it riſes, but it affords no rays of warmth. Some idea may be formed of the quantity of fuel thus waſted in ſmoke, by reflecting on the maſs of ſoot that a few weeks' firing will lodge againſt the ſides of the chimney; and yet this is formed only of thoſe particles of the column of ſmoke which happen to touch the ſides in its aſcent. How much more muſt have paſſed off in the air? And we know that this ſoot is ſtill fuel, for it will burn and flame as ſuch; and, when hard caked together, is indeed very like and almoſt as ſolid as the coal from which it proceeds. The deſtruction of fuel goes on nearly in the ſame quantity in ſmoke as in flame, but there is no compariſon in the difference of heat given. When freſh coals are firſt put on a fire, a conſiderable body of ſmoke ariſes. This ſmoke is, for a long time, too cold to take flame; but if a burning candle is plunged into it, the candle, inſtead of inflaming the ſmoke, will inſtantly be itſelf extinguiſhed. Smoke muſt have a certain degree of heat to be inflammable. As ſoon as it has acquired that degree, the approach of a candle will inflame the whole body, and the difference of the heat which it gives will be very ſenſible. A ſtill eaſier experiment may be made with a candle itſelf. Hold your hand near the ſide of its flame, and obſerve the heat it gives: then blow it out, the hand remaining in the ſame place, and obſerve what heat may be given by the ſmoke that riſes from the ſtill burning ſnuff; you will find it very little: and yet that ſmoke has in it the ſubſtance of ſo much flame, and will inſtantly produce it, if you hold another candle above it ſo as to kindle it. Now the ſmoke from the freſh coals, laid on this ſtove, inſtead of aſcending and leaving the fire, while too cold to burn, being obliged to deſcend through the burning coals, receives among them that degree of heat which converts it into flame; and the heat of that flame is communicated to the air of the room, as above explained.

The flame from the freſh coals laid on in this ſtove, deſcending through the coals already ignited, preſerves them long from conſuming, and continues them in the ſtate of red coals, as long as the flame continues that ſurrounds them, by which means the fires made in this ſtove are of much longer duration than in any other, and fewer coals are therefore neceſſary for the day. This is a very material advantage indeed. That flame ſhould be a kind of pickle to preſerve burning coals from conſuming, may ſeem a paradox to many, and very unlikely to be true, as the doctor tells us it appeared to himſelf the firſt time he obſerved the fact: he therefore relates the circumſtances, and mentions an eaſy experiment, by which his reader may be in poſſeſſion of every thing neceſſary to the underſtanding of it. In the firſt trial he made of this kind of ſtove, which was conſtructed of thin iron plate, he had, inſtead of the vaſe, a kind of inverted pyramid, like a mill-hopper; and fearing at firſt that the ſmall grate contained in it might be clogged by cinders, and the paſſage of the flame ſometimes obſtructed, he ordered a little door near the grate, by means of which he could occaſionally clear it; though after the ſtove was made, and before he had tried it, he began to think this precaution ſuperfluous, from an imagination that the flame, being contracted in the narrow part where the grate was placed, would be more powerful in conſuming what it ſhould there meet with, and that any cinders between or near the bars would be preſently deſtroyed and the paſſage opened. After the ſtove was fixed and in action, he had a pleaſure now and then in opening that door a little, to ſee through the crevice how the flame deſcended among the red coals, and obſerving once a ſingle coal lodged on the bars in the middle of the focus, he obſerved by a watch in what time it would be conſumed: he looked at it long without perceiving it to be at all diminiſhed, which ſurpriſed him greatly. At length it occurred to him, that he had ſeen the ſame thing a thouſand times, in the converſion of the red coal formed in the ſnuff of a burning candle, which, while enveloped in flame, and thereby prevented from the contact of the paſſing air, is long continued, and augments inſtead of diminiſhing, ſo that we are often obliged to remove it by the ſnuffers, or bend it out of the flame into the air, where it preſently conſumes to aſhes. He then ſuppoſed, that to conſume a body of fire, paſſing air was neceſſary to receive and carry off the ſeparated particles of the body: and that the air paſſing in the flame of the ſtove, and in the flame of a candle, being already ſaturated with ſuch particles, could not receive more, and therefore left the coal undiminiſhed as long as the outward air was prevented from coming to it by the ſurrounding flame, which kept in a ſituation ſomewhat like that of charcoal in a well luted crucible, which, though long kept in a ſtrong fire, comes out unconſumed.

This ſtove of Dr. Franklin is very ingenious, and has been much uſed in France, where the management of coal-fires is but little underſtood, and they are therefore induced to uſe ſtoves in preference to open fires, when they burn pit-coals. Dr. Franklin completed the ſtove juſt deſcribed in 1771, and uſed it in London during three winters. While he was in France, he contrived another grate for burning pit-coals, which has the ſame property of burning the ſmoke, and at the ſame time the fire is expoſed in a grate. The grate is a ſhort cylinder, with its axis placed horizontally, and the end turned towards the apartment; one of its circular ends being made with bars, and the other is a back-plate: it is one foot (French) in diameter, and eight inches deep or long between the bars and the back: the ſides and back are of plate-iron, the ſides having holes of half an inch diameter, and three or four inches diſtant from each other, to let in air for enlivening the fire: the back is without holes, and the ſides do not meet at either the top or bottom by eight inches: and this ſquare ſpace is filled with grates of ſmall bars, croſſing from front to back to let in air below, and let out the ſmoke or flame above. The three middle bars of the front grate, that is, the circular end, are fixed; the upper and lower may be taken out and put in at pleaſure, when hot, with a pair of pincers. The whole of this cylindrical grate turns upon pivots fixed in the oppoſite ſides, acroſs the centre of it: the pivots are ſupported by a crotchet, the ſtem of which is an inverted conical tube five inches deep, which fits as many inches upon a pin, which is fixed upright in a caſt-iron plate that lies upon the hearth. In the middle of the top and bottom grates

are fixed small upright pieces, about an inch high, which, as the whole is turned on its pivots, stop it when the grate is perpendicular. By this means the grate can be inverted by turning it over upon its pivots, but as that will present the back-plate to the apartment, it requires to be turned half round horizontally upon the conical pin to bring the front bars to the room.

In making the first fire in the morning with this grate, there is nothing particular to be observed: it is made as in other grates, the coals being put into the cylindrical grate above, after taking out the upper bar, which must be replaced when they are in.

The round figure of the front bars filled with fire, when thoroughly kindled, is agreeable: it represents the great giver of warmth to our system. As it burns down, it leaves a vacancy above, which must be filled with fresh coals, the upper bar is to be taken out, and fresh coals thrown in, the bar being afterwards replaced. The fresh coals, while the grate continues in the same position, will throw up, as usual, a body of thick smoke; but every one accustomed to coal-fires in common grates must have observed, that pieces of fresh coal stuck in below among the red coals, have their smoke so heated, as that it becomes flame as fast as it is produced, which flame rises among the coals, and enlivens the appearance of the fire. Here, then, is the use of this swivel-grate: by a push with the tongs or poker, it can be turned over on its pivots till it is inverted, and the front bars face the back of the chimney; then turn it gently round on its vertical socket or axis, till it again faces the room, whereby all the fresh coals will be found under the live ones, and the greater part of the smoke arising from the fresh coals will, in its passage through the live ones, be heated so as to be converted into flame. By this means much more heat is obtained from them, and the red coals are longer preserved from consuming. This construction, though not so complete a consumer of all the smoke as the vase, is yet fitter for common use, and very advantageous; it gives also a full sight of the fire always, a pleasing object which we have not in the other. It may with a touch be turned more or less from any one of the company that desires to have less of its heat, or presented full to one just come out of the cold; and when the front bars of the grate are supported in a horizontal position, a tea-kettle may be boiled on them.

Notwithstanding the acknowledged advantages of Dr. Franklin's construction of a stove, the expence and trouble of it, and the difficulty of procuring workmen who understood the manner of executing it, have prevented the general use of his stoves. Mr. James Sharp, with a view of obviating these objections and difficulties, has proposed several improvements, for which he has obtained his majesty's patent. According to the method which he proposes, they are easily accommodated to any rooms, where communication can be had with the external air; both to those which have, and those which have not chimnies: so that not only small rooms, but the largest halls, libraries, or churches, may be warmed in a more effectual manner than had ever been done before, and the greatest degree of heat produced from a given quantity of fuel. Mr. Sharp, by adding funnels to the top, renders these stoves fit for any chimney, and by lengthening the funnel, to any place without a chimney. By the hollow base with which his stove-grates are furnished, he is able to apply them with much greater effect to the external air, without any addition of brick-work; and by the alterations in the air-box, a much greater quantity of warm air is introduced than it was possible to introduce in their former state. If a stove of this kind is to be placed in a common fire-place, a hole must be made through the back of the chimney, or through the hearth, to communicate with the external air; and this hole should be made as large as possible, and in a descending position, so that the outward air may ascend towards the stove. The hollow base of the stove must be placed against this hole, so as to cover it completely; and the bottom of the base must be fitted so close to the earth, and pointed with lime or putty, that the air may not pass. Upon the stove there must be put a few feet of iron funnel to reach above the breast of the chimney; and the chimney inclosed by iron plates, so constructed and placed in a square or oblong iron frame, that they may be easily removed when the chimney wants sweeping. By this construction, the warm air, introduced by the stove, will be carried into the room, which would otherwise pass up the chimney, and be lost. But if the stove is to be fixed in a room where there is no chimney, it may be placed in any part of it, where communication may be had with the outward air; and nothing more is necessary than a sufficient length of funnel to carry it through the roof, or wall, or window, or into any other chimney that may be convenient. If the fire-place be too small for the stove, the chimney may be closed by the aforementioned frame and plates, and the stove stand before the fire-place, and the smoke be carried off, by the help of a circular elbow, into the chimney above the mantle-piece. Many of these stoves, it is said, have been lately put up, in order to cure smoky chimnies, and have always succeeded. For farther particulars, see Sharp's Account of the Air-Stove Grates, &c.

The inhabitants of the northern parts of Europe have long been accustomed to the use of stoves in which the fire is shut up, and gives out its heat to a draught or current of air, which is made to pass through proper openings in the stove, and when sufficiently warmed, enters into the apartment. The smoke arising from the fuel is made to pass through a circuitous passage of flues, by which means the greatest part of the heat is absorbed. Stoves on this principle are known in England, but are very seldom used, except for warming of halls, staircases, and passages, in grand houses, as the English are not contented to feel the air warm, unless they see the fire. In Russia, Sweden, and other northern countries, they are indispensably necessary, as without them, it would be impossible to keep the rooms tolerably warm. A common fire-place has too large an opening, and if care be not taken to supply it continually with wood, &c. the heat it produces is hardly sensible, because it follows the current of the air, and is carried off by the smoke. These stoves, on the contrary, retain the heat a much longer time; and as their external parts, and also their flues, are very thin, they communicate their heat very readily, so that with a small quantity of wood, they warm an apartment much more than the fire of a common fire-place would do, with six times the quantity. For it was not sufficient that the inhabitants of these severe climates should discover the most simple means of keeping up in their houses a comfortable degree of heat, it was also necessary that this should be done with the least possible expence of fuel.

The stoves which they employ perfectly fulfil the abovementioned intentions; they are also susceptible of every kind of ornament. The more surface we give to a stove constructed in this manner, the more the heat is increased, consequently we must not be surprised to find that this kind of stove sometimes occupies the whole height of an apartment, its width and depth being proportioned to its height.

The construction of these stoves is simple: they consist of

four, five, or more small chambers, built one above another: the lower one is for the fire which burns in it, and the smoke rising from it enters into the chamber immediately above, then into the third, and from that to the fourth. The passages or holes through which the smoke enters into one chamber from that beneath, are, in all cases, made at the corner of the chamber, opposite to the passage at which the smoke will pass out from the same chamber to the next above it. By this means the smoke is obliged to pass through the whole of the chamber, and has the greatest chance of transmitting its heat. A fire lighted in one of these stoves early in the morning, and with a small quantity of fuel, retains a strong heat during the whole day. The door of the fire-place is only opened to put in wood, and remains afterwards constantly shut. The wood lies upon a grate, consequently it is not buried in and stifled by the ashes. The ash-hole is spacious, and one or two feet in height, according to the capacity of the stove. Two doors are placed at the extremities of the ash-hole, and the current of air is very considerable, by which the smoke is carried up with great force, and the wood burns very briskly.

Stoves of this kind may be advantageously placed in halls, at the bottom of staircases, and in the anti-chambers of great houses: they may also, by proportioning their size to that of the rooms for which they are intended, be made use of in the houses of private persons. To this it may perhaps be objected, that the heat produced from these stoves is unwholesome, because they deprive the air of its moisture; and that the air, by being made too dry, loses its elasticity, in consequence of which, respiration becomes difficult and laborious. These objections would appear of great weight, if we had not the example of the Russians, the Swedes, the Danes, the Germans, and in short of all the inhabitants of the north of Europe, to shew that those who are habituated to such stoves, do not find them unwholesome. If others should be sensible of inconveniencies from the dryness of the air in the apartment, it may be easily removed by the very simple expedient of placing upon the stove a vessel of glass or earthen-ware, which has a large surface, and is very shallow: this being filled with water, will insensibly evaporate, and restore to the air that moisture of which the heat of the stove has deprived it: the air will then recover its elasticity. If orange-trees are exposed to the heat of such a stove, and the fire is not properly regulated, the plants grow yellow and lose their leaves, especially if the air is not changed, which in winter is not very conveniently done; but if a vessel of water be placed upon the stove, the evaporation of the water will preserve the trees.

In a memoir published by M. Guyton in the Annales de Chimie, he has explained the construction of the stoves employed in Sweden, and recommends the adoption of one constructed on the same principle for general use in France.

The memoir is translated in the Repertory of Arts, 1st Series, vol. xvi. The construction of the stove which is there recommended may be improved, to adapt it to our use in England, where pit-coal is used: but the following principles, which the author lays down, are very useful as guides in making all kinds of stoves for warming apartments.

1. Heat is produced only in proportion to the volume of air consumed by the fuel.

2. The quantity of heat produced is greatest, (the quantity and quality of the fuel being the same,) when the combustion is complete.

3. The combustion is the more complete, in proportion as the fuliginous part is longer retained in channels where it may undergo a second combustion.

4. The only useful heat is that sent out into, and retained in the space intended to be heated. The temperature of that space will be higher in proportion, as the current which must be renewed from without to support the combustion, is less enabled to take up in its passage the heat produced.

Hence the following inferences evidently arise:

1. The fire-place ought to be insulated from all bodies that are rapid conductors of heat. All the heat that goes out of the apartment is absolutely lost, unless intentionally directed into another apartment.

2. Heat being produced only by combustion, and combustion being sustained only by a current of air, the current should be brought in by channels, where the needful rapidity may be preserved without being too distant from the space to be warmed, so that the heat it there deposits, may be gradually accumulated in the whole of the insulated furnace, in order afterwards to flow out of it slowly, according to the laws of the equilibrium of that fluid.

3. The wood being so far consumed as to give no more smoke, it is advantageous to close the mouth of these channels, in order to retain there the heat that would otherwise be carried off through the upper flue, by the continuance of a current of fresh air, necessarily of a low temperature.

4. Lastly; it follows from these maxims, that all things being equal, a higher temperature will be obtained, and supported during a much longer time, by forming, in the internal parts of the stove, or under the hearth of a chimney, and in their vicinity, tubes in which the air that comes from without may be warmed before it enters the apartment, to serve the purpose of combustion, or replace that which has been consumed. These have been called *bouches de chaleur* (mouths or apertures of heat); because, instead of contemplating their principal use and intention, it is commonly imagined that they are only made in order to give by their issues a more rapid current to the heat produced. Nor is this idea absolutely devoid of foundation, since the air that issues from them has only changed its temperature, by carrying off a portion of the heat that would have remained in the interior. Those, however, who would proscribe them, as opposing the most important object, which is the retaining of the heat as long as possible, do not consider that they may be closed, and all communication with the external air cut off by a simple slide, and, therefore, it is easy to derive from them every possible advantage without any inconvenience. And we may add, that in small apartments, or such as are accurately closed, they are often indispensibly requisite, if we could avoid being exposed to currents of cold air. Dr. Franklin very justly quotes a Chinese proverb to this effect: "Shun a current of air from a narrow passage as you would the point of an arrow."

The Swedish or Russian stoves, which have chambers for the reception of the flame and smoke, are little known in this country: but those which are in common use in the halls and vestibules of our great houses are French stoves. They differ from the others in having a very great length of small flues or winding passages, through which the smoke passes, and communicates its heat to the air, which circulates in similar passages, until it becomes warmed, and makes its exit through the mouths into the apartment. This method is not so simple as the small chambers or apartments of the Russian stoves, nor is it so good in the long run; because the passages are very liable to become clogged with soot;

and even before they are fo clogged as to intercept the paffage of the fmoke, the tranfmiffion of the heat is much impaired, becaufe the interior furfaces of the flues becoming coated with foot, do not conduct the heat fo rapidly, and in confequence, a great part will ftill pafs out into the chimney. Alfo, thefe flues with fmall paffages require a ftronger draught in the chimney, to make the air pafs through the paffages, than when chambers are ufed.

The Holland iron ftove, which has a flue proceeding from the top, the fire-place and afh-pit being clofed by fmall iron doors opening into the room, comes next to be confidered. It is frequently made of iron-plate, and is moft commonly called a German ftove. Its conveniencies are, that it makes a room warm all over, for the chimney being wholly clofed, except the flue of the ftove, very little air is required to fupply that, and therefore not much rufhes in at crevices, or at the door when it is opened. Little fuel ferves, the heat being nearly all faved; for it radiates almoft equally from the four fides, and the bottom and top, into the room, and prefently warms the air around it, which being rarefied rifes to the ceiling, and its place is fupplied by the lower air of the room, which flows gradually towards the ftove, and is there warmed and rifes in its turn, fo that there is a continual circulation, till all the air in the room is warmed. The air, too, is gradually changed by the ftove-doors being in the room, through which part of it is continually paffing, and that makes thefe ftoves more wholefome, or at leaft more pleafant, than the German ftoves, next to be fpoken of. But they have the inconvenience that there is no fight of the fire, which is in itfelf a pleafant thing, nor can any other ufe be conveniently made of the fire but that of warming the room.

When the room is warm, people not feeing the fire are apt to forget fupplying it with fuel till it is almoft out, then growing cold, a great deal of wood is put in, which foon makes it too hot. The changes of air are not carried on quick enough, fo that if any fmoke or ill fmell happen in the room, it remains a long time before it is difcharged. For thefe reafons, the Holland ftoves have not been much introduced among the Englifh (who love the fight of the fire), unlefs in fome workfhops, where people are obliged to fit near the windows for light, and in fuch places they have been found of great ufe.

The real German ftove is made like a box, one fide wanting, and that fide is built againft the wall of the room. It is compofed of five iron-plates fcrewed together, and fixed fo as that the fuel can be put into it from another room, or from the outfide of the houfe. It is a kind of oven reverfed, its mouth being without and body within the room that is to be warmed by it. This invention certainly warms a room very fpeedily and thoroughly with little fuel: no quantity of cold air comes in at any crevice, becaufe there is no difcharge of air which it might fupply, there being no paffage into the ftove from the room. Thefe are its conveniencies. Its inconveniencies are, that people have not fo much fight or ufe of the fire as in the Holland ftoves, and are moreover obliged to breathe the fame unchanged air continually, mixed with the breath and refpiration from one another's bodies, which is very difagreeable to thofe who have not been accuftomed to it.

This may be remedied by making a fmall aperture into the flue, with a regifter to draw off the air. This kind of ftove is ftill lefs in ufe in England than that which we have before defcribed, and which is generally called the German ftove, although it is ufed by the Dutch inftead of the Germans.

Meffrs. Strutt, in their extenfive cotton-mills at Belper, in Derbyfhire, have employed a kind of ftove which is found to anfwer extremely well; it confifts of what is called a cockle, that is, a fquare cheft or veffel of iron-plate, rivetted together in the manner of a boiler, and fet in a furnace, fo that a fire can be made withinfide of it upon a grate, and the fmoke will pafs off through a fmall paffage into the flue which conducts to the chimney, the paffage of which is regulated by a fliding damper. The cockle is of confiderable dimenfions, as much as four feet fquare and five feet in height, and the fire is made at the bottom of it, upon a grate of about fourteen inches by eighteen, fo that the fire does not any where touch the infide of the cockle, but the heat rifing up therein gives a confiderable and equable heat, without rendering it fo hot as to burn the air which it is intended to warm, for if that is once done the air will be rendered unpleafant.

The cockle is inclofed in a cafing of brick-work, which is of the fame fhape as the cockle, and leaves a fpace all round between of a few inches. This cafe of brick-work is again furrounded by walls of brick-work, leaving a fpace of about eighteen inches all round; and thefe walls are carried up above, to form the chimney or funnel to convey the warmed air up to the feveral apartments of the mill. This chimney is divided, by thin brick partitions, into as many different flues as there are floors to be warmed; and a fmall opening is made, with a regifter, from each flue into the apartment it is intended to fupply. This opening is made clofe to the floor; and in order to make a change of the air, ventilators are placed high up in the apartment, fo as to be near the ceiling.

This divifion of the chimney into feveral different flues is intended to equalize the fupply of air to the feveral apartments, and by this means the upper apartments are equally well fupplied with warm air as thofe below.

In order to make the air pafs in contact with the furface of the heated cockle, a horizontal partition is built in the fpace between the chimney and the brick-cafing of the cockle. The level of this partition is at about one half the height of the cockle, and its effect is to divide the brick-cafing of the cockle into two halves, one above the partition and the other below. The cold air is freely admitted into the lower part of the chimney beneath the partition, but cannot efcape into the chimney above it, without entering into the fpace between the cockle and its brick-cafing, through a number of fmall openings made in it beneath the horizontal pofition; and in thus paffing in contact with the furface of the cockle the air becomes heated, and paffes out again, through openings in the brick-cafing, into the chimney above the partition. In order to make the cold air ftrike more forcibly againft the heated furface of the cockle, a fmall iron tube is fitted through each of the openings in the lower part of the cafing, and the ends of thefe tubes approach very near to the furface of the cockle. Mr. Strutt has introduced this kind of ftove into the new Infirmary at Derby, and in feveral other fimilar inftitutions it has been adopted with great fuccefs.

In 1799, Mr. James Burns of Glafgow took out a patent for an improved ftove, or fire-grate, to burn with an open fire: his ftove has a very elegant appearance, and feveral advantages. The object of the improvement was to prevent the heat generated by combuftion, and thrown out into the apartment by radiation, from being unneceffarily wafted by the draught of air for the fupport of the fire, as is ufual in ftoves or grates of the common conftruction; where all the air that goes to maintain the combuftion is furnifhed from the warm air in the room, the wafte of which is fupplied by the exterior cold air, which comes pouring into the room at the

bottoms of the doors, or by the ſides of the windows, and thereby undoes a great part of the effect that otherwiſe would be produced by the fire. To accompliſh this intention, the air that maintains the fire in the improved ſtoves is brought through a tube, which is called the air-tube, from the outſide of the houſe, and may be made to paſs between two of the joiſts, (where the floors and ceilings are cloſe enough to allow this,) ſo as to be brought to the bottom bars of the grate, without having any communication with the interior air of the room; while, at the ſame time, the grate and parts connected with it are ſo conſtructed, that when the fire is not wiſhed to be ſupplied with cold air from the outſide of the houſe, the paſſage may be ſhut more or leſs perfectly by means of a valve, a ſmall door, a cock, or any ſimilar contrivance. When convenience does not admit of the air-tube being carried to the outſide of the houſe, it may be carried to a cellar, larder, or ſtair-caſe, and the ſame end will be gained, with this farther advantage, that ſuch cellar, or other apartment, will be always well ventilated, and prevented from acquiring or retaining any unhealthy or diſagreeable ſmells.

The principle is to ſupply the fire with air from without the room or apartment, ſo as to prevent the warm air of the room from being drawn to the fire-place and hurried up the chimney, while, at the ſame time, all the advantages of open grates may be enjoyed.

The form of Mr. Burns' ſtove is that of a vaſe or urn placed in the chimney-place, which is made circular, to form a niche for its reception. The urn is open at top, and the ſides are formed of open work or grating, with a grated bottom, forming a ſufficient ſpace to contain the fire; but the pedeſtal and lower part of the vaſe are made cloſe, to prevent the entrance of air to the fire, except that which paſſes up from the air-tube through the hollow pedeſtal; and within this pedeſtal is an air-valve, which opens and ſhuts by a regiſter, to regulate the entrance of the current from the open air. In the pedeſtal of the vaſe is a drawer, to receive the aſhes. The niche or chimney in which the vaſe is placed, has the uſual opening at top to carry off the ſmoke. The air for the ſupport of the fire enters from the external air, through the tube or air-pipe before deſcribed, and paſſes into the hollow pedeſtal of the vaſe; and having paſſed through the hollow neck or ſtem of the vaſe, it finds no difficulty in paſſing up through the bottom of the grate, the back or ſide of the aſh-drawer next which the aperture is being made low, to allow it to flow in freely. The grate and its internal cavity may be of any convenient form, but circular or elliptical will anſwer beſt, eſpecially when another improvement is applied. This is a glaſs talc or iron-work fence or ſcreen, to prevent thoſe dreadful accidents which ſo frequently occur of ladies' or children's clothes being ſet on fire by ſparks from the grate. Where this ſafe-guard fence or ſcreen is wiſhed to be applied, the inſide of the chimney where the grate is to ſtand muſt be a ſemi-cylinder, or nearly ſo, with a lining or cover, made of metal, at ſuch a diſtance from the ſemi-cylindrical wall or niche in which the ſtove is placed, as to give ſufficient room for allowing the ſafe-guard or fence to be ſlid round into it, when the fire is wiſhed to be left open to introduce freſh fuel, or when the drawer with the aſhes is to be removed. The fence is a frame-work of metal, which, when filled up with glaſs, or with wire-work, forms a portion of a cylinder, anſwerable to the curvature of the ſpace between the back of the chimney and the lining above-mentioned, made in one or two pieces, and moving in a circular groove in the hearth, which ſerves to conduct it into its place behind the grate, when the fire-place is wanted to be left open, as before-mentioned. The top of the front of the opening (the chimney-piece) projects in a circular form, or is furniſhed with an added projection, made of metal, and furniſhed with a circular groove on its under ſurface, of the ſame radius as the groove in the hearth, for the purpoſe of guiding the upper part of the frame of the guard. The glaſs with which the frame of the guard is filled may be ſtained or painted: complete ſafety is thus obtained, and, at the ſame time, the comfort ariſing from the view of a cheerful fire is not prevented by the interpoſition of any opaque body. But for nurſeries or the like, where convenience and ſafety are more the objects than elegance or luxury, the frame-work may be filled up with wire-work.

Inſtead of ſuch grooves at top and bottom for the fence to move in, the fence itſelf may be furniſhed with a groove at its top and one at its bottom, to receive any projecting piece of metal, or other ſubſtance of a proper curvature; or its bottom groove may receive the upper edge of the fender, which, being made to a proper curve, and properly adjuſted and kept in its place, will anſwer the ſame end. But whichever of theſe ways be followed, or whatever other method of conſtruction (for it may eaſily be varied to anſwer circumſtances), rollers or caſtors ſhould be provided at the lower part of the fence, to make it move with greater eaſe, either to the front of the grate, or into the ſpace between the back of the chimney and the lining above-mentioned. Where either the glaſs or the wire-work frame, or both of them, are meant to be applied to ſquare or rectangular chimnies, without the trouble of giving them a ſemi-cylindrical form, the lining to receive the fence or fences may be introduced at the ſides, or jambs, of ſuch chimnies; or the fence may be made to riſe, by means of pullies, into the wall above the opening, or be ſlid ſideways into the walls at the ſides of the openings.

Beſides the advantages already pointed out as connected with them, theſe ſtoves poſſeſs alſo the following; any room or apartment may be heated by their means with a much ſmaller quantity of fuel than by common open fires; at the ſame time, the advantage of ſeeing the fire is not loſt, as in cloſe ſtoves, for theſe grates have ſide as well as bottom bars, which allow the radiant heat and light to be thrown out into the room, without any impediment; and, in fact, large rooms, halls, and the like, which by the uſual methods can hardly be warmed, or made at all comfortable in cold weather, may, by means of theſe improvements, be heated as effectually as the ſmalleſt apartment; for when their full effect is wanted to be procured, it is only neceſſary to keep the fence in its receſs, that even that portion of heat which would be kept back by the interpoſed glaſs or wire-work, may be thrown out into the room, and perform its office.

In 1804, Mr. Joſhua Jowett of London obtained a patent for a very ſimilar contrivance, which he called a fire-guard ſtove, which is intended to prevent accidents from ſparks of fire flying out. The ſtove itſelf is an open fire, and is uſually made of a cylindrical form, the axis of the cylinder being vertical. One half of the cylinder which faces the apartment is made with bars at the lower part, to contain the fire, and an opening over them to feed it. The back part of the cylinder is made of caſt-iron plate; but, inſtead of the brick-work being built up cloſe round the back, a ſmall ſpace is left to receive the guard. The weight of the ſtove or grate is ſupported upon a vertical iron bar, which is in the centre, or axis of the cylinder, which forms the ſtove, and the guard ſwings round upon this bar as a centre, and being a half-cylinder of wire-work, can be brought in front to incloſe

the fire, or it can be turned round behind the ftove out of fight.

The fire-guard may be fixed to any ftove which will admit of two centres or pivots being placed in a perpendicular line in the back of the ftove, to fufpend the fire-guard, and guide its motion; and the ftove muft admit of grooves on either fide, for the guard to pafs through, as the levers will direct. The principle of the action of the fire-guard, is that of being united to two centres or pivots, placed perpendicular one to the other; and it is connected to the two centres fixed to the ftove by means of two lever-cranks, one end of which is fixed to the guard, and the other end of each to the centres or pivots, by which the guard fwings in a rotatory motion, paffing through a groove formed in the ftove on either fide, to fwing before the fire when required, and is brought into ufe by means of a handle or nob, faftened to the front edge of the frame of the guard for that purpofe; or, inftead of drawing it out with the hand, as before defcribed, it may be brought into ufe by means of a fpring faftened to the crank, and preffing againft the cheek or back of the ftove, to throw the guard forward. The fame effect may be produced by means of a balance faftened to any part of the fire-guard, and working with a line or chain over pullies fixed to the ftove, or by means of the combined force of the fpring and balance.

Mr. Allan Pollock took out a patent, in 1807, for a ftove which is very fimilar to the Swedifh ftoves, having chambers through which the fmoke is fucceffively conveyed, and gives out its heat to the air of the apartment in which it is placed: in addition to this, the ftove is made to give a conftant current of warmed air; for this purpofe, the cold air is made to enter and circulate through winding paffages, fituated in the back of the fire-grate, or fpace in which the fire burns, and the fame paffage is continued, by an iron tube, through the fmoke-chambers up to an air-chamber fituated in the top, from which it paffes into the apartment. Thefe ftoves are made of caft-iron; but, to prevent the air receiving any taint from paffing in contact with the hot iron, Mr. Pollock propofed to apply a compofition to the cores of the moulds in which the pipes are to be caft, which compofition will become vitrified by the heat of the melted iron, when the fame is poured into the mould, and will form a glafly or vitrified lining to the tubes, and prevent the actual contact of the air with the iron. Thefe ftoves anfwer very well.

A very important improvement in thofe fire-places for burning of coal, which are generally called regifter-ftoves, has been lately made by Mr. John Cutler of London, for which he had a patent in 1815. The ftoves conftructed by him are nearly fuch as are known by the name of regifter-ftoves, being made of caft-iron plate to inclofe the fire-place at the back and fides, but open in front to the apartment; leaving only a paffage for the fmoke through a regifter, at the upper part of the inclofed fpace. Mr. Cutler's improvement confifts in applying to fuch grates or ftoves a chamber, or magazine, fituated beneath the grate (or the fpace inclofed by grating) in which the fire is to burn. This chamber is to contain a magazine of fuel fufficient to fupply the combuftion for a whole day, or other required fpace of time: the bottom plate of the chamber is moveable; and by means of a wheel and axle, the fuel contained in the magazine can be elevated, fo as to introduce a portion of the fuel into the grate at the lower part, or from beneath; and thus, from time to time, replace the fuel which is confumed, without the trouble of occafionally throwing on coals.

In order to make the fire burn, the flue or entrance to the chimney muft be of fuch a conftruction, as will produce the moft efficient draught or current of air to pafs through and acrofs the top of the fire. This improvement of introducing a fupply of fuel into the grate from beneath, caufes the fire to burn clear and with little fmoke; becaufe the fmoke, or gas, which iffues from the newly introduced fuel, when it is firft heated, muft of neceffity afcend through the burning fuel, and be thereby confumed. Another improvement is to reduce the fire, or extinguifh it, when it is left for the night. This is done by lowering down the whole of the fire from the grate into the chamber, or magazine, beneath the grate: the fupply of air is thus interrupted, and the fire is completely inclofed in a deep cheft, fo that it is impoffible fparks can fly out, and the fire foon becomes extinguifhed. The advantages of thefe improvements are by no means trifling. By burning the fmoke, the whole effect of the fuel confumed is produced; and were this invention univerfally introduced into London, that pernicious footy atmofphere in which it is hidden would be fo improved, as to be equally pure with that of Paris, or other continental cities, where wood alone is ufed for fuel The burning of the fmoke renders the fweeping of the chimnies unneceffary, and the danger of fire from the foot contained in the flue is avoided: alfo chimnies which throw out fmoke into the room will, in almoft all cafes, be cured by this improvement, becaufe the quantity of air or gas which muft pafs through the chimney is fo fmall. To avoid the trouble of throwing on coals, and to have at all times a bright and chearful fire, are matters of convenience, but are not wholly to be overlooked: and, laftly, to have the means of extinguifhing the fire, when it is left for the night, is a moft important improvement; when it is confidered that, amongft the fires which happen every year in London, how many break out in the hours when the fires are left, and a great proportion are doubtlefs occafioned by fires left unextinguifhed.

The machinery for raifing up the moveable bottom of Mr. Cutler's ftove is very fimple. The magazine-chamber is compofed of iron plates fcrewed together, and the moveable bottom is fitted to it, fo as to leave as fmall a fpace round the edges as poffible. A bar is fixed acrofs, beneath the bottom plate; and the ends of this bar pafs through flits, or narrow openings, in the fide plates of the chamber. To the extremities of the bar the ends of two chains are attached, and the upper ends of thefe chains are made to wind upon the ends of a horizontal axle, which extends over the top of the ftove, fo as to be within the chimney, and out of fight. The axle is turned round by a face or crown-wheel, fixed upon the extremity of it, and the teeth thereof are engaged by the teeth of a fmall pinion, the axis of which comes through the iron work of the ftove; and the end has a fmall fquare hole in it, to receive a fquare or key upon a fmall winch handle. By means of this handle, the iron axle is turned round, and winds up the chains, fo as to elevate the bottom plate of the magazine, and thereby raife up a portion of frefh fuel into the lower part of the grate, where it is burned, as before mentioned; and the fmoke which firft iffues from the coal rifes through the fire, and is thereby confumed.

Mr. Cutler has made a great number of thefe ftoves, which are found to anfwer very well: they have all the fame properties as Dr. Franklin's cylindrical grate, but in a greater degree; and the fire can be fupplied with frefh coals at the lower part, without the trouble of inverting the grate.

Stoves, *American*, are contrivances for warming of

rooms, &c. by a continual introduction and exchange of dry fresh air. These stoves are called American, because the first patterns in cast-iron upon this principle were the invention of Dr. Franklin, who then resided in Philadelphia. See FIRE-*Places*.

Steam-tin

Stream-*Tin*, in *Mineralogy*. Particles or maſſes of tin-ore found beneath the ſurface of alluvial ground in low ſituations, or in vallies, are called *ſtream-tin* in Cornwall and Devonſhire, from the proceſs uſed to ſeparate the earthy matter from it, which conſiſts in paſſing a ſtream of water over it. The particles of ſtream-tin are generally rounded by attrition. The ore is of the beſt quality, and is ſometimes intermixed with particles of native gold. See the following articles, and Tin.

Stream-*Works*. The alluvial repoſitories of tin-ore are called ſtream-works. (See the preceding article.) They conſiſt of beds or ſtrata of particles, and rounded pieces of tin-ſtone, covered by alluvial depoſits of ſand or gravel. The formation of theſe repoſitories in Cornwall is owing to the ſoft decompoſing ſtate of the rocks, which are interſected by metallic veins. Tin-ſtone or tin-ore poſſeſſes great hardneſs and ſpecific gravity, and when carried down by rivers or floods, is ſeparated from its matrix by the action and re-action of the water, and ſpread into layers, which are afterwards covered by beds of ſand, clay, or gravel, over which another layer of ſtream-tin is ſometimes found covered with an upper depoſit of alluvial matter. That ſtream-tin has been carried down to the ſituations in which it now occurs, is proved from another circumſtance,—fragments and maſſes of rock are found with it, which, in many inſtances, ſerve to identify the rock from whence it came, being different from the rocks in the vicinity, and often poſſeſſing ſome characteriſtic appearance by which it can be immediately known to the miners of the country. Almoſt all the rocks of Cornwall are in a ſtate of rapid diſintegration, and have evidently been much higher than at preſent at ſome former period. Many of the ſtream-works or repoſitories are of very ancient date, as they occur conſiderably below the preſent level of the rivers. Human ſkulls, and the horns of the elk, or ſtag, have been found in the beds of ſand which cover them. In the ſtream-works near St. Auſtle, pieces of native gold, from the ſize of a bean to that of an hazel-nut, were occaſionally found; and a piece of a vein of quartz from the ſame place, about one-third of an inch thick, containing imbedded globules of native gold, the ſize of large ſhot, is in the poſſeſſion of Mr. Hennah, of Plymouth: the latter is important, as proving that gold once exiſted in regular veins. In St. Blazey Moor there is a depth of twenty feet of alluvial ſoil. The firſt ſtratum next the ſurface is compoſed of gravel reſting upon mud; the ſucceeding ſtratum is gravel, containing a little tin-ore: this lies upon a bed of dark combuſtible peat-earth. Immediately under this lies a bed of ſtream-tin, about five feet thick. Great part of this ſtream-tin had been wrought out at a very remote period, and before iron inſtruments were in uſe; for ſeveral wooden pick-axes, made of oak, holm, and box, were diſcovered in it a few years ſince. Stream-works ſometimes extend under the ſea on the coaſt of Cornwall. One of the moſt remarkable of theſe works is in a branch of Falmouth harbour. That variety of tin-ore called wood-tin is found in ſtream-works, but is not at preſent met with in regular tin-veins.

In ſome parts of the mining diſtricts of Derbyſhire, lead-ore is met with in alluvial depoſitions. Mr. Farey, in his Derbyſhire Report, p. 373, mentions a maſs of lead-ore, 25lbs. weight, being taken out of a gravel at the top of a hill in the village of Wyanton, which proves that maſſes of lead-ore have in former times been carried far from their native ſituations; and the reaſon why they are not more frequently found, ariſes from their being ſofter and more periſhable than tin-ore. Many of the alluvial repoſitories of gold have a ſimilar origin to the ſtream-works of Cornwall. The gold, being heavy and imperiſhable, has remained, while the materials in which it was imbedded have been waſhed away. See Vein.

STREAMING, or Stream-*Works*, denotes the management of the ſtream-tin. The firſt part of this buſineſs, after ſecuring the ground which contains it, is to ſink a hatch, or ſhaft, three, five, or ſeven fathoms deep, to the rocky ſhelf or clay on which the tin is ſtratified. If, upon trying a ſhovel of it, it be worth working, the operator digs an open trench in the loweſt part of the valley, which he calls a *level;* and this ſerves to drain off all water from the workings. Thoſe places that are rich in ore are called *beubryle*, or living-ſtreams. The ſtreamer next carries off what he calls the over-burden, *i. e.* the looſe earth, rubble, or ſtone which covers the ſtream; and the ſtream-tin is dug up and waſhed at the ſame time, by caſting every ſhovel of it as it riſes into a *tye*, which is an inclined plane of boards for the water to run off, about four feet wide, four high, and nine feet long: in which, with ſhovels, they turn it over and over again, under a caſcade of water which waſhes through it, and ſeparates the waſte from the tin, till it becomes one half

tin. The beſt of the tin is collected by its ſuperior gravity, in the head of the tye, under the caſcade; and the refuſe and ſoil are caſt into the beds of adjacent rivers, or buried under the gravel and ſtones that form the interior ſtrata. This kind of tin is dreſſed by waſhing it again in a ſmaller tye, called a *gounce*, with a leſs current of water, and greater care. The richer part is put into large vats, and the waſte is dreſſed again, till what remains becomes refuſe; the tin is then ſifted through wood or wire ſieves, which ſeparate the greater and ſmaller particles: the ſmalleſt tin is put into another firmly weaved horſe-hair ſieve, called a *diluter*, by which it is made ſaleable.

Some of the nodules of tin are ſmelted as they come out of the tye; but thoſe which are mixed with water, as well as the refuſe of the poor tin, which were in the tails of the tye and gounce, are triturated and pulverized in the ſtamping-mill, ſo that all waſte may be cleared from the tin by ſeveral ablutions, as in the dreſſing of mine-tin. See *Dreſſing of* ORES.

Beſide theſe ſtream-works, there is another ſort, occaſioned by the refuſe from the ſtamping-mills, &c. which are carried by the rivers into the lower grounds, and after lying ſome years and collecting there, yield ſome money to the laborious dreſſers, called *lappiors*, probably from the Corniſh word *lappior*, or dancer, from the method of moving up and down with naked feet in the buddles, to ſeparate the tin from the refuſe. Stream-tin is then carried to the blaſt-furnace, called the blowing-houſe, in which a fire is made with charcoal, excited by two large bellows, which are worked by a water-wheel. The tin and charcoal are laid in a furnace, made by moor-ſtones and clay, well cemented and cramped together with iron, called the caſtle, ſtratum ſuper ſtratum, in ſuch quantities, that from 8 to 12 cwt. of tin, by the conſumption of from 18 to 24 ſixty-gallon packs of charcoal, may be ſmelted in a tide, or twelve hours' time. The tin is forced out by the blaſt of the bellows, through a hole at the bottom of the earth, into a moor-ſtone trough, called the *float*; whence it is laded into leſs troughs or moulds, each of which contains about 3 cwt. of metal, called ſlabs, blocks, or pieces of tin, in which ſize and form it is ſold in every market in Europe. This, on account of its ſuperior quality, is known by the name of *grain-tin*, which formerly fetched a price of 7*s*., and of late is advanced to 10*s*. or 12*s*. more *per* cwt. than mine-tin is ſold for, becauſe it is ſmelted from a pure mineral by a charcoal fire; whereas mine-tin is uſually corrupted with ſome portion of mundic, or other minerals, and is always ſmelted with a bituminous fire, which communicates a harſh ſulphureous quality to the metal. Pryce's Mineral. p. 136, &c.

STRENGTH, *vis*, force, or power.

It has been faid that the ftrengths of different animals of the fame fpecies, or of the fame animal at different times, are in a triplicate proportion of the quantities of the mafs of their blood: the whole ftrength of an animal being the force of all the mufcles taken together; therefore, whatever increafes ftrength, increafes the force of all the mufcles, and of thofe ferving digeftion, as well as others. See MUSCLE.

Yet, though the truth of this obfervation be allowed, the quantity of blood may be increafed in fuch circumftances as to abate the ftrength. The equilibrium between the blood and veffels being deftroyed, wonderfully leffens the ftrength. The fudden fuppreffion of perfpiration, though it increafes the quantity of the blood, as it muft confiderably do fo, by Sanctorius's calculation, yet it leffens the ftrength; becaufe the retained matter, being what ought to be evacuated, fo alters the texture of the blood, as to make it unfit for mufcular motion.

Suppofe the increafe of quantity to be connected with an extraordinary vifcidity, the quantity of fmall feparable parts decreafing as the vifcidity increafes, the quantity of animal fpirits feparated in the brain will be lefs; and the tenfion of the fibres being in proportion to the animal fpirits forced into them, they will not be able to counterpoife the great weight of the blood, and fo the ftrength will be diminifhed.

Bellini proves, that if the blood be fo vitiated as to increafe or diminifh ftrength, it amounts to the fame as if the blood were in a natural ftate, but its quantity increafed or diminifhed in the fame proportion: fo that the blood, when vitiated, may fo impair the ftrength of the mufcles, as even to fpoil digeftion; and yet, in fome cafes, it may be fo vitiated as to help digeftion, and increafe ftrength.

M. de la Hire, in a calculation of the ftrength of a man in drawing and bearing, fhews, that the ftrength of an ordinary man walking in an horizontal direction, and with his body inclining forwards, is only equal to twenty-feven pounds; which is much lefs than one would have imagined.

He adds, that this force would be much greater, if the man were to walk backwards; and that it is for this reafon, that watermen fetch their oars from before backwards: and though, he obferves, the gondoliers of Venice fetch them the contrary way, yet this is, becaufe they choofe to lofe the advantage of ftrength, to have that of feeing the place they are going to, in the numerous turns and canals they there meet with.

It is known by experience, that a horfe draws, horizontally, as much as feven men; confequently, his ftrength will be 189 pounds. A horfe, as to pufhing forwards, has a great advantage over a man, both in the ftrength of its mufcles, and the difpofition of the whole body; but the man has the advantage over the horfe in afcending. M. de la Hire fhews, that three men, laden with 100 pounds a-piece, will afcend a pretty fteep hill with more eafe and expedition than a horfe laden with 300 pounds.

Hakewell, in his Apology, p. 238, furnifhes us with abundance of inftances of extraordinary ftrength.

STRENGTH *of a Sentence*, in *Grammar* and *Rhetoric*, denotes fuch a difpofition or arrangement of the feveral words or members, as fhall bring out the fenfe to the beft advantage, render the impreffion which the period is defigned to make moft full and complete, and give every word and every member their due weight and force. A fentence, as Dr. Blair obferves, may be fufficiently clear, and poffefs the requifite compactnefs or unity; and yet, by fome unfavourable circumftance in its ftructure, it may fail in that ftrength or livelinefs of impreffion, which would have been produced by a more happy arrangement. The *firft* rule, which this writer gives, for promoting the ftrength of a fentence, is to diveft it of all redundant words and members. The *fecond* rule is to attend particularly to the ufe of copulatives, relatives, and all the particles employed for tranfition and connection. The *third* rule is to difpofe of the capital word or words in that part of the fentence in which they will make the fulleft impreffion. The *fourth* rule is to make the members of fentences go on rifing and growing in their importance above one another; which kind of arrangement is called a *climax* (which fee): in other words, a weaker affertion or propofition fhould never come after a ftronger one; and when a fentence confifts of two members, the longeft fhould, generally, be the concluding one. The *fifth* rule is to avoid concluding fentences with an adverb, a prepofition, or any inconfiderable word; becaufe fuch conclufions are always enfeebling and degrading. Befides particles and pronouns, any phrafe, which expreffes a circumftance only, always brings up the rear of a fentence with a bad grace. Another rule, relating to the ftrength of a fentence, is this: that, in the members of a fentence, when two things are compared or contrafted to each other, where either a refemblance or an oppofition is intended to be expreffed, fome refemblance in the language and conftruction fhould be preferved; for when the things themfelves correfpond to each other, we naturally expect to find the words correfponding too. We might here add, that the found, harmony, and eafy flow of the words and members of fentences, contribute to promote their ftrength and effect. This rule comprehends the choice of words, and their arrangement; the order and difpofition of the members, the cadence or clofe of fentences, and the found of words as adapted to their fignification. For the illuftration and application of thefe rules, we refer to Blair's Lectures, vol. i. and Murray's Grammar, vol. 1. See STYLE and NUMBERS.

STRENGTH *and Strefs of Materials*, in *Mechanics*, is a fubject of very confiderable importance, and one which, of all the branches of this ufeful fcience, is the leaft underftood. We have, indeed, two or three diftinct theories by different authors, for eftimating the ftrength of beams, and other materials, according as they are placed in this or that pofition; but it unfortunately happens that we owe all thefe theories to men who have not themfelves made any experiments, and have, therefore, no better foundation than mere hypothefis, and confequently are not only difcordant amongft each other, but totally at variance with practical refults. The authors to whom we more particularly allude in this place, are Galileo, James Bernoulli, Leibnitz, Euler, and Lagrange; names certainly of the firft eminence as philofophical mathematicians, and whofe refpective inveftigations, while we only contemplate the analytical proceffes of them, are highly honourable to the genius and talents of their authors: but when we confider them with reference to their practical application, we are obliged to admit that they are almoft entirely ufelefs. Had the materials the properties thefe authors fuppofe, *viz.* were they perfectly elaftic in one cafe, or perfectly rigid and incompreffible in another, then we fhould doubtlefs find the refults fuch as have been deduced; but we know that, practically, none of thefe properties are found to have place. We know of no bodies either perfectly hard, or perfectly elaftic; we know of no bodies that are either

wholly incompreſſible, or inextenſible; and, conſequently, of none to which theſe theories will apply: being each founded upon ſome hypotheſis, which neceſſarily involves one or other of theſe principles as their baſes.

There is, however, another claſs of men to whom we are indebted for many varied experiments; but not one of them, we believe, has ever attempted to eſtabliſh any theory, as founded upon the facts which theſe experiments have eſtabliſhed. Of the latter claſs are more particularly to be diſtinguiſhed Mariotte, Parent, Belidor, Muſchenbroeck, and Buffon, particularly the latter, who, with Du Hamel, was employed by the French government in making experiments on a very conſiderable ſcale; but unfortunately M. Buffon conducted them rather as a natural philoſopher than as a mathematician, and, therefore, did not deduce from them thoſe uſeful practical reſults, which might *à priori* have been expected. Our countryman, Emerſon, alſo made ſome experiments on the ſtrength of various materials; but little confidence is, we believe, to be placed on his determinations. They appear to have been made in too groſs a manner to be at all depended upon, to form the groundwork of any calculations; as, in ſome caſes, they nearly double the ſtrength which has been found by other and more accurate experiments; while, in ſome, they make it not more than half. Thus, Emerſon ſays, that a piece of oak, a yard long and an inch ſquare, when ſupported at its two ends, bore, before breaking, 330 pounds; whereas Belidor makes the ſtrength only 187 pounds; and we have repeated the experiments on ſeveral pieces of oak of the ſame dimenſion, and have found a very accurate agreement between them, and the mean given by the latter author, *viz.* 187 pounds. The direct ſtrength of coheſion of the different woods given by Muſchenbroeck and Emerſon are alſo much at variance with each other; and though we ought not perhaps, in ſuch a caſe, to give our entire confidence to either, yet the care Muſchenbroeck appears to have taken, and the minuteneſs with which he deſcribes the proceſſes he employed, cannot but incline us to adopt his reſults, in preference to Emerſon's, till ſome farther experiments have been made, that, from their number and accuracy, may inſpire us with greater confidence. Such a courſe of experiments is now carrying on at the Royal Military Academy, Woolwich, by Mr. Barlow of that inſtitution; and as nothing will doubtleſs there be wanting to render the courſe complete, either with regard to the ſelection of proper woods, or the accuracy of the workmanſhip that may be required, the publication of them will doubtleſs be very intereſting, as the means of ſupplying a great deſideratum amongſt the ſcientific engineers of this country. "This ſubject," ſays Dr. Robiſon, "is of ſo much importance, that in a nation ſo eminent as this for invention and ingenuity in every ſpecies of manufactures, and in particular ſo diſtinguiſhed for its improvements in machinery of every kind, it is ſomewhat ſingular that no writer has treated of it in the detail, which its importance and difficulty demand. The man of ſcience, who viſits our great manufactories, is delighted with the ingenuity which he obſerves in every part, the innumerable inventions which come even from the individual artiſans, and the determined purpoſe of improvement and refinement which he ſees in every work-ſhop. Every cotton-mill appears an academy of mechanical ſcience; and mechanical invention is ſpreading from theſe fountains over the whole kingdom. But the philoſopher is mortified to ſee this ardent ſpirit ſo cramped by ignorance of principles, and many of theſe original and brilliant thoughts obſcured and clogged with needleſs and even hurtful additions, and a complication of machinery which checks improvement, even by its appearance of ingenuity. There is nothing in which this want of ſcientific education, this ignorance of principle, is ſo frequently obſerved, as in the injudicious proportion of the parts of machines, and other mechanical ſtructures; proportions and forms of parts, in which the ſtrength and poſition are in no wiſe regulated by the ſtrains to which they are expoſed, and where repeated failures have been the only leſſons."

Without entering here upon the ſubject of corpuſcular attraction, and the law of coheſion which the particles of bodies obſerve, according to their different arrangements, a topic that would carry us far beyond the limits we can aſſign to this article, and on which, after all, ſo little ſatiſfactory information is to be expected, we ſhall proceed to examine the different ſtrains to which a body may be expoſed, and its tendency to reſiſt fracture, according to its magnitude, form, and poſition.

A piece of ſolid matter may be expoſed to four different kinds of ſtrain, *viz.*

1. It may be torn aſunder by ſome force applied in the direction of its length; as in the caſe of ropes, ſtretchers, king-poſts, tie-beams, &c.

2. It may alſo be cruſhed by a force applied in the direction of its length; as in the caſe of pillars, poſts, and truſs-beams.

3. It may be broken acroſs by a force acting perpendicularly to its length; as in joiſts, levers, &c.

4. It may be wrenched or twiſted by a force acting in a kind of circular direction at the extremity of a lever, or otherwiſe; as in the caſe of the axle of a wheel, the nail of a preſs, &c.

On the direct Coheſion of Bodies.—The firſt of theſe ſtrains is by far the moſt ſimple, as to its phyſical operation; though it is that of all others, perhaps, that comes leaſt under the conſideration of a mechanic or engineer: and when it is the ſubject of contemplation, if any former experiment can be had recourſe to, it is ſufficient for his purpoſe; as no poſſible cauſe can be aſſigned, nor any reaſon offered, for ſuppoſing but that, in ſuch caſes, the ſtrength varies directly as the area of the ſection of fracture, and is totally independent of the length or poſition; except, indeed, ſo far as the former may increaſe the weight or force, when the body is ſuſpended in a vertical direction, or in any other poſition where the weight of the body itſelf increaſes the force applied. Abſtracting from this, every part is equally liable to fracture, being throughout ſtretched by the ſame force. But this ſuppoſes a perfect uniformity of corpuſcular action, or of the attraction of coheſion, which is probably not the caſe in any body in nature; and, therefore, as the longeſt body, may be ſuppoſed to offer the greateſt diverſity in this reſpect: it may hence happen that the longeſt body is the weakeſt, and it is probably to this circumſtance we muſt attribute the popular notion of our mechanics, that a long rope is eaſier broken than a ſhorter one of equal quality and thickneſs. It is a fact perhaps drawn from experience, but it is one which cannot be introduced into the ſcience of mechanics; for we muſt there ſuppoſe the body of uniform texture, and draw all our inferences from that ſource; and this obviouſly leads us to the above concluſion, *viz. the ſtrength of bodies, expoſed to ſtrains in the direction of their length, is directly proportionate to their tranſverſe area, whatever may be their figure, length, or poſition.*

As to the irregularities to which we have above alluded, they doubtleſs ariſe from a thouſand circumſtances, with which we are wholly unacquainted; in metals, it depends

upon their purity, the heat at which they are melted, the moulds in which they are caſt, the manner in which they are left to cool, and many others, which totally eſcape our obſervation, ſince they produce different degrees of coheſion between particles, which, as far as our obſervation can extend, are circumſtanced in every reſpect in the ſame manner, being all blended in one maſs, and undiſtinguiſhable the one from the other.

It has been aſcertained from experiment, that by forging a metal, or by frequently drawing it through a ſmall hole in a ſteel-plate, its coheſion is conſiderably increaſed; a fact which, though it ſeems to have excited ſome aſtoniſhment, appears to us to be perfectly reconcileable with what might *à priori* have been expected from the increaſed denſity which this operation is known to produce. Admitting the particles to be placed at equal diſtances from each other, after wire-drawing or forging, as we ſuppoſe them to be before, their lateral diſtances will decreaſe as the cube root of their denſities, and conſequently the number that are brought in contact in equal ſections, are as the $\frac{2}{3}$d power of the denſity; the ſtrength, therefore, ought to vary in the ſame ratio: as to the diſtances in the direction of the length, we do not conceive that it increaſes the ſtrength; it may render the ſubſtance leſs liable to rupture in the firſt inſtance; but if, as in all probability is the caſe, the particles are ultimately removed to a greater diſtance before the fracture takes place, the ſame ultimate force will be requiſite to ſeparate the parts, however cloſe the contact might be in the original ſtate of the body; that is, when firſt ſubmitted to the experiment.

We are unacquainted with the real increaſe of denſity that may be obtained by the proceſſes above alluded to; and more particularly with the lateral approach of the particles, which may be greater than would ariſe from a uniform diſtribution of them; and are therefore unable to ſay how far the increaſed ſtrength agrees with what we have hinted may ariſe from the increaſed contiguity of the particles. Lead, which is ſaid to become rarer by wire-drawing, has its coheſion tripled; gold, ſilver, and braſs, have alſo their coheſion nearly tripled; and copper and iron have theirs more than doubled. How far theſe facts can be ſatisfactorily explained by the greater contiguity of the particles *laterally*, we cannot pretend to ſay, but it certainly will account for a conſiderable part of the increaſed ſtrength.

Experiments on the direct coheſion of all bodies, and particularly metals, are attended with conſiderable difficulty, in conſequence of the enormous weights that are requiſite for producing ſeparation in bars of any conſiderable dimenſion: we have, however, a few reſults of this kind, which we owe to Muſchenbroeck, and other experimentaliſts, the principal of which are contained in the annexed table, all reduced to the ſection of a ſquare inch.

Metals.		Lbs.
Gold caſt		20,000 24,000
Silver caſt		40,000 43,000
Copper caſt	Japan	19,500
	Barbary	22,000
	Hungary	31,000
	Angleſea	34,000
	Sweden	37,000
Iron caſt		42,000 59,000
Iron-bar	Ordinary	65,000
	Stirian	78,000
	Beſt Swediſh and Ruſſian	84,000
	Horſe-nails	71,000
Steel-bar	Soft	120,000
	Razor-tempered	150,000
Tin caſt	Malacca	3,100
	Banca	3,600
	Block	3,800
	Engliſh block	5,200
	Engliſh grain	6,500
Lead caſt		860
Regulus of antimony		1,000
Zinc		2,600
Biſmuth		2,900

It is very remarkable, that almoſt all mixtures of metals are ſtronger, or more tenacious, than the metals themſelves, much depending upon the proportion of the ingredients, and theſe proportions are different in different metals. The following are ſome of thoſe which Muſchenbroeck aſſerts to produce the greateſt ſtrength.

	Lbs.
Two parts of gold with one of ſilver	28,000
Five parts of gold with one of copper	50,000
Five parts of ſilver with one of copper	48,500
Four parts of ſilver with one of tin	41,000
Six parts of copper with one of tin	41,000
Five parts of Japan copper with one of Banca tin	57,000
Six parts of Chili copper with one of Malacca tin	60,000
Six parts of Swediſh copper with one of Malacca tin	64,000
Braſs conſiſting of an unknown proportion of zinc and copper	51,000
Three parts of block-tin with one of lead	10,200
Eight parts of block-tin with one of zinc	10,000
Four parts of Malacca tin with one of regulus of antimony	12,000
Eight parts of lead with one of zinc	4,500
Four parts of tin with one of lead, and one of zinc	13,000

Theſe reſults are very uſeful, provided they could be ſecurely depended upon; but we could wiſh to ſee ſimilar experiments repeated by other philoſophers: not that we wiſh to undervalue the labours of Muſchenbroeck, to whom the arts are much indebted for many valuable deductions, but ſo much irregularity takes place in experiments of this kind, that it is only in a multiplicity of them, complete accuracy, or even an approach towards it, is to be obtained.

The gun-founder might derive conſiderable information from a well-directed courſe of experiments of this kind, as well as the plumber and engineer: it appears from the above, that a mixture of copper, whoſe ſtrength does not exceed 37,000 lbs., with tin, whoſe ſtrength is 6000 lbs., a mixture is produced, whoſe ſtrength is from 60,000 lbs. to 64,000 lbs., at the ſame time that it is harder, and eaſier wrought: and as to the objection that has been advanced againſt it, of being more fuſible, we ſuſpect it is nothing more than a falſe idea ariſing out of a very common error, that field-ordnance is liable to become fuſible with rapid firing: we have been informed by very experienced artillery officers, that nothing of this kind ever happened, the damage which the piece ſuſtains at the muzzle being merely due to the rubbing and knocking of the ball in its paſſage out of the gun.

Having ſaid thus much with regard to the direct coheſion of metals, we muſt now attend to another very important ſubject; *viz.* the ſtrength of timber.

The coheſion here is probably of a very different kind, and ſubject even to more inequalities than that of metals; much depends upon the ſoil where the tree grows, and a conſiderable difference is found between different parts of the ſame

tree; *viz.* whether it comes from near the root, or the top, or from the middle or fides; and even whether it grew on the north or fouth fide.

1. The wood immediately furrounding the pith or heart of a tree, is faid by fome to be the weakeft, particularly if the tree is old; others, efpecially Buffon, affert the contrary; the fact probably is, that up to a certain age it is ftrongeft at the heart, but that afterwards thefe parts become weaker, or begin firft to feel that decay which ultimately pervades the whole. In many experiments which we have made, we have always obferved that the heavieft pieces (and there is a very confiderable difference in this refpect in different parts of the fame tree) are the ftrongeft; and, generally fpeaking, the part neareft the centre and towards the root has the greateft fpecific gravity.

2. The wood of the north fide of all trees in our climates is faid to be weaker than that of the fouth, and the fouth-eaft fide the ftrongeft: we are, however, much inclined to doubt the fact, as it relates to foreft-trees. In trees particularly fituated, with regard to expofure on one part more than another, fomething of the kind may have place; but trees in a foreft, which experience very little difference in this refpect, we are inclined to think, from fome obfervations, have but little difference of ftrength depending upon their northern or fouthern direction. It is true, generally, that that wood is the ftrongeft whofe annual plates are thickeft, the ligneous fibres being ftronger than the trachea, or air-veffels; and, therefore, the more of the fibrous parts there are contained in any given dimenfion, the greater is the ftrength: but this is much more obvious in fome woods than in others, and moft of all, perhaps, in afh, in which we have feen a very remarkable difference in this refpect. In very clofe-grained wood it is fcarcely perceptible.

The only author who has enabled us to judge of the accuracy of his experiments is Mufchenbroeck, who has defcribed very minutely his apparatus, and his method of performing the experiments. The pieces he employed for this purpofe were parallelepipedons, cut down in the middle to $\frac{1}{4}$th of an inch fquare, or $\frac{1}{16}$th of an inch fection. Thefe refults, reduced to the fection of a fquare inch, are as follow:

	Lbs.
Locuft-tree	20,100
Jujeb	18,500
Beech oak	17,300
Orange	15,500
Alder	13,900
Elm	13,200
Mulberry	12,500
Willow	12,500
Afh	12,000
Plum	11,800
Elder	10,000
Pomegranate	9,750
Lemon	9,250
Tamarind	8,750
Fir	8,330
Walnut	8,130
Pitch-pine	7,650
Quince	6,750
Cyprefs	6,000
Poplar	5,500
Cedar	4,880

Emerfon, in his Mechanics, gives us alfo a feries of refults, but they are unlike the former, as they do not exhibit the utmoft ftrength, but what may be fafely fufpended on a fquare inch; yet as we may prefume that each of thofe weights are in the fame proportion to the greateft ftrength, they ought to enable us, in fome meafure, to compare the relative ftrengths of the different woods given by thefe two authors. Emerfon's table is as follows; *viz.*

	Lbs.
Oak, box, yew, plum-tree	7850
Elm, afh, beech	6070
Walnut, plum	5360
Red fir, holly, elder, plane, crab	5000
Cherry, hazel	4760
Alder, afh, birch, willow	4290

With regard to the abfolute refults in thefe two tables, we do not, in courfe, look for uniformity; the one exhibiting the ultimate ftrength, and the other the weight which a rod of an inch fquare may fupport with fafety: but in the relative ftrength of the different woods, fome coincidence might have been expected; we find, however, confiderable difference in this refpect. The latter author gives us no particulars, and we are therefore rather inclined to give the preference to the former, who has been very minute in his defcription, as well as careful in making the experiments; yet fome fubfequent experimentalifts have not been able to find equal ftrength: thus M. Petit fays, on the authority of his own experiments, and thofe of M. Parent, that the utmoft ftrength of a fquare inch of oak does not exceed 8640 lbs.; whereas Mufchenbroeck makes it 17,300lbs.; and we muft add, in confirmation of the former, that in the experiments to which we have before adverted, as at this time in progrefs at the Royal Military Academy, Woolwich, the ftrength of oak has been found but little exceeding 9000 lbs.; the fpecific gravity of it being 774. We have not this datum in either of the above cafes; yet we conceive it to be a very important one, as we have always found the ftrength of wood of the fame kind, to depend a great deal upon its weight or fpecific gravity. The fame experiments give for the ftrength of afh 17,000 lbs., and fir from 10,000 lbs. to 13,000 lbs., both confiderably different from Mufchenbroeck's tabular refults. The pieces from which thefe weights were found were cylindrical, very accurately turned to one-third and one-fourth of an inch in diameter; but to avoid any errors that might have place in gauging the diameters, their circumferences were taken by winding a fine filk thread ten times round them, and then dividing the length of it by 10 for the circumference.

On the Refiftance of Bodies, when preffed longitudinally.— It is obvious that a body, when preffed endwife, by a fufficient force, may be crufhed and deftroyed; and this may take place, either by a total feparation of the matter of which it is compofed, or by bending it, whereby it is broke acrofs: if the length or height of the body is very inconfiderable with regard to its other dimenfions, the former is the almoft certain refult; but if its length be much more than its breadth and thicknefs, it generally bends before breaking, and in this cafe the operation is not very different from what takes place in beams fupported at each end, and loaded in the middle; a fubject which will be treated of in a fubfequent part of this article. We have fome very intricate analytical inveftigations on this fubject by Euler and Lagrange. Thefe authors have both treated the problem on the principles firft promulgated by James Bernoulli, in his inveftigation of the properties of the elaftic curve; but as we doubt very much whether they can be applied to any ufeful practical operations, we muft beg to pafs them over in this place, by merely referring fuch of our readers who are defirous of confulting the inveftigations of thefe two very able mathematicians, to the original works. Euler's firft memoir will be found in the appendix to his "Methodus

inveniendi lineas curvas maximi et minimi, &c." 1744. A second memoir is published in the Berlin Transactions for 1757, and a third in the Acta Petro. 1778. Lagrange's papers are given in the Turin Memoirs for 1770-1, and in the Memoirs of Berlin for 1769.

As to the experiments that have been made on this kind of strain, there are few from which much practical information can be obtained. M. Petit says, that his experiments, and those of M. Parent, shew that the force necessary for crushing a body is nearly equal to that which will tear it asunder. He says that it requires something more than 60lbs. on every square line of sound oak to crush it. But experiments made on such small pieces cannot be depended upon; and when they are made on pieces of greater dimensions, the weights become so enormous, as to render them nearly impracticable; it is therefore fortunate that we have little occasion for very accurate information on this head: what it is more desirable to be acquainted with is, the resistance which a pillar or post will offer to compression before bending, the length being taken into consideration; for it is obvious, both from theory, as well as from a practical view of the subject, that the length of the beam must be an important datum in this kind of strain, although it is not in the former, *viz.* in opposing being drawn asunder; it is therefore very defective to state the requisite forces in both cases to be equal, or indeed to state any proportion whatever between them.

M. Girard, in his "Traité Analytique de la Résistance des Solides," Paris, 1798, details a great variety of experiments made on beams of fir and oak of considerable dimensions, by means of a certain machine constructed for the purpose. But as these experiments were not made so much with a view of breaking the pieces submitted to the pressure, as to measuring their deflections, and estimating what the author calls, after Euler, their absolute and relative elasticity; they do not furnish us with the kind of results above alluded to, as having been attempted by MM. Petit and Parent.

Through the whole course of M. Girard's experiments, much irregularity was observed, so much, indeed, as to render it very doubtful whether any number of experiments could furnish us with certain and conclusive results; and if experiments fail in this respect, it is wholly useless to look to any assistance from long and laborious analytical investigations. The following table contains many of the most important experiments of this author on oak-beams; the first column registers the number of the experiments; the second, third, and fourth, the length, depth, thickness, and weight of the beams; the fifth and sixth the distance of the greatest deflection from the bottom or foot of the beam; the former in the direction of the greatest thickness or depth; and the latter in the direction of the less thickness or breadth; the seventh and eighth columns contain the measure of the greatest deflection, or versed sine of the curve; the former of the depth, and the latter of the breadth; the ninth column exhibits the weights under which the several deflections were observed, and the tenth and last column the time between the first weight being applied and the observation. It should be observed, that M. Girard has given several more measures of deflections, weights, &c. than we have copied; we have, in all cases, taken his first two and last two, and omitted the intermediate ones.

The experiments marked with the * broke under the last registered weight; the others did not, and most of the latter nearly recovered their original form after being unloaded for some hours. The deflections marked + and − are those in which the beam took a double curvature.

The other experiments of this author (the details of which occupy nearly 50 quarto pages) were made on the transverse strain, or rather on the deflection caused in beams by loading them in the centre with different weights, their extremities being supported on two props.

The oak-beams were the same which had been submitted to the longitudinal pressure, as exhibited in the following table, and which were not broken in those experiments; the third table contains the results of similar experiments on fir-beams of larger dimensions; and the two subsequent tables, similar ones on what the French workmen call *bois de brin*, that is, pieces which have been simply squared from the branches, or trunk, corresponding with what our workmen call *spars*.

In all these cases, the deflection was found to follow very nearly the ratio of the weights with which they were loaded, multiplied by the square of the length of the piece, and to be inversely as the square of the depth into the breadth. The fir-beams gave much more uniform results than those of oak, which is accounted for from the more regular and uniform organization of the former wood.

M. Girard endeavours to connect the results with those on the longitudinal pressure, for which purpose he gives us the following formulæ, *viz.* let f denote half the length of a beam, supported at each end and loaded in the middle, and let half that weight be denoted by P, and b the quantity of the beam's deflection; also π the semi-circumference of a circle, whose diameter is 1. then the

$$\textit{absolute elasticity}\ \mathrm{E}kk = \frac{\mathrm{P}f^3}{3b};$$

and the weight Q, under which the same beam will begin to curve, when pressed endwise, will be expressed by

$$\mathrm{Q} = \frac{\pi^2\,\mathrm{E}kk}{4f^2};$$

or, by substituting for E k k, we have

$$\mathrm{Q} = \frac{\pi^2 . \mathrm{P} . f}{12\,b}.$$

We cannot, however, say how far this formula will apply, it being very difficult to ascertain the commencement of deflection in the actual experiment.

M. Girard gives us also two other formulæ, for estimating the deflection of oak and fir beams, when loaded in the middle by a weight, and supported at each end, *viz.*

$$\text{for oak}\quad \frac{\mathrm{P}f^3}{3b} = \frac{(11784451)\ (f + 0.3)\ a\,h^2}{1.3},$$

$$\text{for fir}\quad \frac{\mathrm{P}f^3}{3b} = (8161128)\ a\,h^2;$$

where P is half the weight, f half the length, b the deflection, h the depth of the beam, and a its breadth.

These apply only to rectangular beams; and, in order to render them general, the author uses the principles of Leibnitz, whereby the errors of the latter are connected with them in such a manner as to render the formulæ entirely useless for practical cases.

Girard's Experiments on Oak-beams, preffed in the Direction of their Length.

No. of Experiments.	Length in Metres.	Depth in Metres.	Breadth in Metres.	Weight in Kilograms.	Height of Deflection from the Foot in Metres. In the Direction of its Depth.	Height of Deflection from the Foot in Metres. In the Direction of its Breadth.	Verfed Sine of greateft Deflection. In the Direction of its Depth.	Verfed Sine of greateft Deflection. In the Direction of its Breadth.	Weight in Kilograms.	Time in Hours.
1	2.5979	0.1580	0.1285	54.7844	1.0689	1.2989	0.0068	- -	17,320	0.83
					- -	- -	0.0090	0.0068	29,691	2.08
					- -	- -	0.0090	0.0090	37,429	2.91
					- -	- -	0.0113	0.0090	42,418	9.58
*2	2.5979	0.1624	0.1060	44.0231	1.1907	1.2989	0.0056	0.0045	11,993	2.05
					0.9742	- -	0.0068	0.0079	25,664	9.16
					- -	- -	+0.0068	0.0135	42,514	10.83
					- -	- -	−0.0068			
3	2.5979	0.1579	0.1015	42.0665	0.6495	- -	+0.0023	- -	11,991	0.83
					1.9484	- -	−0.0017	- -		
					1.7861	- -	−0.0113	- -	28,575	9.58
					1.6237	- -	−0.0282	- -	31,339	10.41
4	2.5979	0.1330	0.0992	34.2402	1.2989	1.2989	0.0113	0.0079	11,993	6.66
					1.2989	1.2989	0.0180	0.0124	17,341	8.33
					1.2989	1.2989	0.0479	0.0124	22,939	10.0
*5	2.5979	0.1308	0.1060	33.2620	1.2989	1.1366	0.0169	0.0068	11,996	6.66
					1.2989	0.9742	0.0372	0.0113	17,341	8.33
					deflections not obferved.				22,931	8.75
6	2.2731	0.1556	0.1308	42.5557	- -	1.1366	- -	0.0028	22,939	6.66
					1.2989	1.1366	0.0023	0.0045	28,619	9.58
					1.2989	1.2989	0.0023	0.0034	39,630	18.33
					deflections not obferved.				52,270	22.50
7	2.2731	0.1579	0.1285	45.9747	- -	- -	- -	- -	17,317	0.83
					1.6237	0.9742	0.0040	0.0040	22,934	2.08
					1.2989	1.2989	0.0169	0.0045	47,047	20.83
					1.2989	1.2989	0.0186	0.0090	47,032	23.33
	2.2731	0.1556	0.1038	35.7076	1.6327	1.2989	0.0062	0.0034	17,320	12.08
					1.6327	1.2989	0.0096	0.0034	22,936	12.91
					1.6327	1.2989	0.0181	0.0045	28,616	13.75
					deflections not obferved.				33,120	13.95
*9	2.2731	0.1579	0.1015	33.7511	1.4613	1.2989	0.0068	0.0068	17,321	12.08
					1.2989	1.1366	0.0124	0.0045	22,940	12.58
					deflections not obferved.				28,626	14.50
10	2.2731	0.1262	0.1015	30.3271	1.4613	1.1366	0.0079	0.0062	11,999	10.00
					1.4613	0.9742	0.0079	0.0062	15,025	12.91
					1.4613	0.9742	0.0113	0.0062	17,320	22.91
					1.2989	0.9742	0.0135	0.0068	20,326	25.83

TABLE—*continued.*

No. of Experiments.	Length in Metres.	Depth in Metres.	Breadth in Metres.	Weight in Kilograms.	Height of Deflection from the Foot in Metres. In the Direction of its Depth.	Height of Deflection from the Foot in Metres. In the Direction of its Breadth.	Versed Sine of greatest Deflection. In the Direction of its Depth.	Versed Sine of greatest Deflection. In the Direction of its Breadth.	Weight in Kilograms.	Time in Hours.
11	1.9484	0.1556	0.1330	44.5122	0.9742	0.9742	−0.0045	0.0079	17,321	7.08
					0.9742	0.9742	−0.0045	0.0090	22,940	10.00
					0.9742	0.9742	0.0034	0.0090	28,622	19.16
					0.9742	0.9742	0.0051	0.0101	33,105	26.66
12	1.9484	0.1579	0.1308	37.6642	0.9742	0.9742	0.0079	0.0130	22,940	20.00
					0.9742	0.9742	0.0079	0.0130	33,123	25.00
					0.6495	0.0146	+0.0068	0.0146	39,637	27.91
					1.6237		−0.0023			
13	1.9484	0.1579	0.1015	30.8362	0.6495	0.6495	0.0045	0.0056	17,321	2.08
					0.6495	0.6495	0.0062	0.0068	22,939	3.33
					0.6495	0.6495	+0.0068	0.0108	39,456	33.33
							−0.0023			
*14	1.9484	0.1601	0.1015	32.7728	1.4613	0.9742	0.0045	0.0040	11,973	10.00
					1.4613	0.9742	0.0045	0.0045	17,274	27.50
					1.6237	1.2989	0.0113	0.0090	28,509	37.50
					- -	- -	- -	- -	32,996	50.41
15	1.9484	0.1330	0.1060	28.3705	1.2989	0.6495	0.0056	0.0045	17,294	10.00
					0.9742	0.6495	0.0051	0.0045	22,899	28.33
					1.6237	1.4342	+0.0068	0.0118	46,952	86.66
					0.3247		−0.0011			
16	1.9484	0.1285	0.1082	26.9030	0.9742	0.9742	0.0045	0.0056	11,998	18.33
					0.9742	0.9742	0.0056	0.0079	17,317	20.00
					0.6495	0.6742	+0.0045	0.0135	37,273	92.50
					0.2435		−0.0011			
17	2.2731	0.1579	0.1082	35.7076	0.6495	.9742	−0.0029	0.0028	11,998	10.00
					- -	.6495	- -	0.0034	17,320	20.00
					1.6237	.9742	0.0056	0.0045	33,120	52.50
					1.4613	.9742	0.0113	0.0051	39,630	57.50
*18	2.5979	0.1579	0.1353	50.8712	0.9742	1.2989	0.0051	0.0034	11,999	10.00
					0.9742	1.2989	0.0068	0.0056	17,321	20.00
					1.9484	1.2989	−0.0079	0.0079	33,120	47.91
					1.6327	1.2989	−0.0146	0.0079	37,305	50.83
19	2.5979	0.1872	0.1579	72.8827	1.2989	- -	0.0023	- -	11,997	10.00
					1.2989	- -	0.0034	- -	17,318	20.00
					0.3297	1.2929	−0.0023	0.0056	62,513	110.0
					0.9742		+0.0023			
20	2.5979	0.1894	0.1579	65.5456	1.2989	- -	0.0023	- -	11,998	10.00
					1.2989	- -	0.0023	- -	17,321	22.91
					0.3247	1.6237	+0.0056	0.0101	62,534	122.0
					1.9484	1.6237	−0.0226	0.0135	62,468	212.0

The reader will perceive conſiderable irregularity in many of the above experiments, both with regard to the height at which the deflection begins, the quantity of it, and its direction; being ſometimes in the line of the greateſt thickneſs, and ſometimes in that of the leaſt, but more commonly in both. It will alſo be obſerved, that ſome of the beams broke under leſs preſſures than others, of the ſame or leſs dimenſions, bore without any apparent injury.

We cannot enter here into a farther explanation of the experiments, nor ſhall we attempt to illuſtrate the theory which the author ſeems deſirous of eſtabliſhing, both becauſe it would carry us beyond our limits, and that, at the ſame time, we are very doubtful of its accuracy. When the only deduction is a mean drawn from a great variety of very irregular reſults, it is of little uſe to the practical engineer. He had much better be furniſhed with the ſeveral experiments, and thence form his own judgment of what dimenſions will beſt ſuit his purpoſe, according to the particular object he may have in view; and in this reſpect, *viz.* in the detail of the experiments, rather than in theory deduced from them, we ought to eſtimate the value of this author's labours, which have been very great, and are deſerving of high commendation.

The only experiments, beſides the above, that appear entitled to any notice, are thoſe of M. Ganthey, in the fourth volume of Rozier's Journal de Phyſique.

This engineer expoſed to great preſſures ſmall rectangular parallelepipeds, cut from a great variety of ſtones, and noted the weights which cruſhed them. The following table exhibits the medium reſults of many trials, on two very uniform kinds of free-ſtone, one of them among the hardeſt, and the other among the ſofteſt, uſed in building.

The firſt column contains the length, the ſecond the breadth, and the third the area, of the ſection, in lines, or twelfths of inches; the fourth is the weight in ounces which cruſhed them; and the fifth the whole numbers, which nearly expreſſes the number of ounces borne by each ſquare line.

	Lines.	Lines.	Sq. lines.	Oz.	
Hard ſtone.			54	736	12
		12	96	2625	24
		16	128	4496	36
Soft ſtone.	9	16	144	560	4
	9	18	162	848	4½
	18	18	324	2928	9
	18	24	432	5296	12

Very little can be deduced from theſe experiments. The firſt compared with the third, and the fifth with the ſixth, ſhould furniſh ſimilar reſults; for the firſt and fifth are reſpectively half of the third and ſixth, but the third is three times ſtronger than the firſt, while the ſixth is only double the ſtrength of the fifth.

It appears, however, that the ſtrength increaſes faſter than the area of the ſection, and that a ſquare line can carry more and more weight, as it is a part of a larger ſurface; but in the experiments on the ſoft ſtone, the ſtrength ſeems to increaſe more nearly in proportion to the ſurface.

Theſe experiments are doubtleſs upon too ſmall a ſcale to be of any eſſential ſervice to the practical engineer: the pieces of ſtone ought certainly to have had a ſquare inch of ſurface at leaſt, and the weight which would have been neceſſary to cruſh them would not have been ſo enormous, but that ſome very ſimple mechanical apparatus might have been made ſufficient for the purpoſe; and if any tolerable uniformity were obſerved in pieces of that ſize, ſome uſeful concluſions might poſſibly be drawn from the experiments. But we think little confidence can be placed in thoſe made on pieces of ſuch ſmall dimenſions. According to M. Ganthey's deductions, a pillar of hard ſtone of Givry, whoſe ſection is a ſquare foot, will bear with perfect ſafety 664,000 pounds; and its extreme ſtrength is 871,000 pounds; and the leaſt, as obſerved in his experiments, 460,000 pounds. The ſoft bed of Givry ſtone had for its leaſt ſtrength, on the ſame ſurface, 187,000 pounds; for its greateſt, 311,000 pounds; and for its ſafe load, 249,000 pounds.

Good brick will carry with ſafety 320,000 pounds, on a ſquare foot; and chalk, 9000 pounds.

Beſides the above experiments on the force neceſſary for cruſhing ſtone pillars, M. Ganthey made others on their ſtrength of direct coheſion, as well as on the tranſverſe ſtrain. He found that a priſm of hard Givry ſtone, of a foot ſection, was torn aſunder by a weight of 4600 pounds; and that, when firmly fixed in a horizontal wall, it will be broken by a weight of 56,000 pounds, ſuſpended at the diſtance of twelve inches from its inſertion; and if it reſts on two props, a foot diſtant from each other, it requires 206,000 pounds laid on its centre to produce the fracture. We ſhall merely obſerve, that theſe reſults are very incongruous with each other; and that ſome miſtake, or ſome very unaccountable irregularity, muſt have taken place in the experiments, that it ſhould require ſo much more weight, acting at the diſtance of a foot, to produce the ſeparation, than when the force acted at no mechanical advantage whatever, as in the caſe of direct coheſion.

Very different to the above have been the reſults of ſuch experiments as we have performed on different kinds of wood. An oak rod of an inch ſurface requires a weight of about 9000 pounds to produce the fracture; while the ſame, or a ſimilar rod, fixed in a wall, and acted upon at the diſtance of a foot, is broken with a weight of 132 pounds; and fir, which will bear 13,000 pounds on a ſquare inch, ſuſpended vertically, is broke with a weight of 136 pounds. We are aware that, in different materials, a different law may be obſerved between the ſtrength of direct coheſion and the reſiſtance of the ſame body to a tranſverſe ſtrain; but it is abſolutely impoſſible to have the difference ſtated by M. Ganthey. A good courſe of experiments is, therefore, much wanted on materials of this kind.

We ought perhaps to obſerve, that we have not had an opportunity of conſulting the work in which M. Ganthey's experiments were originally given. Our numbers are drawn from Dr. Robiſon's account of them, in the work to which we have before referred.

On the tranſverſe Strain and Strength of Beams, &c.—The moſt uſual ſtrain, and, therefore, the one with which it is moſt important for us to be well informed, is that by which a body is broken acroſs, from the action of a weight acting perpendicularly or obliquely to its length, while the beam itſelf is ſupported at its two extremities, or by one end being firmly fixed in a wall, or other ſolid and immoveable body. Galileo, to whom the phyſical ſciences are ſo much indebted, was the firſt who connected this ſubject with mathematical principles, and endeavoured to trace the law of ſtrength which different bodies poſſeſſed, in proportion to their length, breadth, depth, form, and poſition. It appears that this philoſopher was led to theſe inveſtigations, in conſequence of a viſit that he made to the arſenal of Venice, and the reſults of which were publiſhed in his Dialogues in 1633. Galileo ſuppoſed ſolid bodies to be

composed of small fibres applied parallel to each other, and sought, or assumed, at first, the force with which they resisted the action of a power to separate them, applied parallel to their length; and thence readily deduced that their resistance, in this direction, was directly as the area of the transverse perpendicular section, that is, to the number of fibres which compose the body. He then considered in what manner the same fibres would oppose a force applied perpendicular to their length; and concluded, that when a beam is fixed horizontally in a wall, the resistance of the integrant fibres is proportional to their sum, multiplied into the arm of a lever, which is always a certain part of the vertical dimension of the solid in its plane or area of fracture. This general principle is, in fact, adopted by most writers on this subject; but that which is peculiar to Galileo is, that he supposed the resistance of each fibre to be the same, and, therefore, as wholly independent of their quantity of extension at the moment of rupture. Supported on the result of these reasonings, and guided by the genius for observation, which he possessed in an eminent degree, he illustrated many of the proceedings of nature, which the more ancient philosophers had left unnoticed; as well as certain anomalies, or which then appeared as such, in the works of art. To some of his observations on this subject we may have occasion to advert, in a subsequent part of this article; but at present we shall confine ourselves to the illustration of his particular theory. It will be proper, however, first to define a few of the terms which more commonly occur in the course of our investigations.

We have already explained what is to be understood by the absolute strength of a body, or its strength of direct cohesion; *viz.* the number of pounds weight necessary to produce a fracture of its parts, when applied in a direction parallel to its length.

And as to the words *strength*, *stress* or *strain*, they are used, the former to denote the force or power with which any mass or body resists a breach or change in its state, which a pressure or stroke upon it has a tendency to produce; and the latter are used indiscriminately to express the force which is exerted on any such mass, and tending to break it. Thus, every part of a pillar is equally *strained* by the load which it supports; and hence it is evident that we cannot make any structure fit for its purpose, unless the *strength*, in every part, be at least equal to the *stress* laid on, or the *strain* excited in that part; and hence the necessity of an acquaintance with the nature of the resistance of bodies, in order that we may not have our structure deficient in strength, nor over-burdened with useless materials; which latter, carried to excess, may be the cause of producing the mischief they were intended to prevent.

In order to illustrate the theory of resistances of bodies, when exposed to a transverse strain, according to the hypothesis of Galileo, let R S T V, (*Plate* XXXIX. *Mechanics, fig.* 1.) represent a solid wall, or other immoveable mass, into which the beam, C G, is inserted; and let W represent a weight suspended from its other extremity. Then supposing the beam to be insuperably strong in every part, except in the vertical section A B C D, the fracture must necessarily take place in this section only, and, according to the hypothesis of this author, it will turn about the line C D, whereby the fracture, commencing in the line A B, will terminate in the former, C D. Galileo also further supposes, that the fibres, forming the several horizontal plates or lamina from C D to A B, act with an equal force in resisting the fracture, and, therefore, differ in their energy only as they act at a greater or less distance from the fulcrum C D. Now, from the known principles of the lever, it is obvious that the equal forces acting at the several distances oa, ob, oc, od, &c. of the lever oe, will offer resistances proportional to their respective distances; and, therefore, that the sum of all these resistances, that is, of the constant force, f, of each particle into its respective distance, is the force which must be overcome by the weight W, acting at the distance o K.

This will, perhaps, be better understood by referring to *fig.* 2, where A C I F represent a section of the beam C G, and r, r', r'', &c. are so many small equal weights acting at the several distances C m, C m', C m'', &c.; then denoting each of these weights by the constant quantity f, the sum of all their energies or resistances will be expressed by $AC \cdot f + Cmf + Cm'f + Cm''f +$ &c. $= f \times (AC + Cm + Cm' + Cm'' +$ &c.) This, however, supposes the section A C D B (*fig.* 1.) to be rectangular, or that the number of fibres in each horizontal lamina are equal in number. When the beam is triangular, cylindrical, or having any other than a rectangular section, the several small weights must be proportional to the breadth of the section at the point where it is supposed to act: the illustration, in this case, however, is equally obvious.

Since then the whole resistance to fracture is made up of the sum of the resistances of every particle or fibre acting at different distances on the lever C A, which is supposed to turn upon C as a fulcrum, there must necessarily be some point in that lever, in which, if all the several forces were united, their re-action to the weight W would be exactly the same as in the actual operation, ***and this point is the centre of gravity of the section***, as is readily demonstrated as follows.

Let A B C (*fig.* 3.) represent the section of any beam whatever, F H any variable absciss $= x$, and D E the corresponding double ordinate $= y$; then, by what is stated above, the energy, or force, of all the particles in the line D E, will be as D E × H F, or as xy, and consequently the fluxion of that force will be $yx\dot{x}$, and therefore the sum of them $= \int yx\dot{x}$, or fluent of $yx\dot{x}$; also $\int y\dot{x} =$ area A B C; whence, assuming G to be the centre of energy sought, we must have $FG \times \int y\dot{x} = \int yx\dot{x}$, whence

$$FG = \frac{\int yx\dot{x}}{\int y\dot{x}},$$

which is the well-known formula for the centre of gravity.

Hence results the following very simple theory for the strength of beams placed firmly in a solid wall, or other immovable body; *viz.* that "the weight necessary to produce the fracture, is to the direct force of cohesion of all the fibres in the section, as the distance of the centre of gravity of that section from the point where the fracture terminates, to the length of the beam, or distance of the weight from the same point."

Nothing more simple can be desired as a general theory, but unfortunately it is founded on hypotheses which have nothing equivalent to them in nature: in the first place, it assumes the beam to be inflexible, and insuperably strong, except at the section of fracture; secondly, that the fibres are inextensible and incompressible; and thirdly, that the beam turns about its lowest point, when fixed at one end, or its upper, when supported at both; and, consequently, that every fibre in the section is exerting its force in resisting extension; and, lastly, (if this be not implied in our second objection,) that every fibre acts with equal energy, whatever may be its quantity of extension. Now, with regard to the first of these suppositions, it is obvious that no beam of timber, nor any other body, is perfectly inflexible; nor

any (and more particularly timber) whoſe fibres are not both extenſible and compreſſible; and, conſequently, a beam of ſuch matter will not turn about its loweſt point as a fulcrum; and, laſtly, the ſuppoſition of every fibre exerting a conſtant reſiſtance, independently of its quantity of extenſion, if it be not incorrect, is of that nature which ought not to be aſſumed, without firſt being verified by experiment.

Such being the inaccuracy of Galileo's hypotheſis, it neceſſarily happened, as ſoon as it was attempted to compare it with experiments, (which the author himſelf had never done,) that it was found defective. The firſt, we believe, who did this was Mariotte, a member of the French Academy in 1680; and what he publiſhed on the ſubject engaged the attention of many celebrated mathematicians of that day, particularly Leibnitz; who, after examining the theory of Galileo, publiſhed his own thoughts on the ſubject. He had frequently remarked that the rupture of a body, whatever it may be, is always preceded by a certain degree of inflection, from which he concluded, contrary to the former opinion, that every body was compoſed of extenſible fibres, and aſſuming the principle firſt laid down by Dr. Hooke, *viz.* "ut tenſio ſic vis," he concluded that every fibre, inſtead of acting with an equal force, exerted a power proportional to its quantity of extenſion, or, which is the ſame, proportional to its diſtance from the line about which the beam was ſuppoſed to turn; but he ſtill conſidered the fibres to be incompreſſible, and conſequently that the beam turned about its loweſt point. Thus, to uſe a ſimilar illuſtration in this caſe that we have done in the former; inſtead of the fracture being oppoſed by the action of the equal weights at r, r', r'', r''', &c. as in *fig.* 2, the re-action was ſuppoſed to be equal to the ſeveral equally decreaſing weights r, r', r'', r''', &c. *fig.* 4. The only alteration which this new ſuppoſition introduced into the final reſults was, the removal of the centre of energy, G, to a point nearer or farther from the centre of motion, according to the figure of the body; and this new point is found *to be diſtant from that axis, by a quantity equal to the product of the diſtances of the centre of gravity, and centre of oſcillation of the area of fracture, from the axis of motion, divided by the depth of the ſection.*

For let A B C (*fig.* 3.) repreſent the ſection of fracture on any beam; $FH = x$, any variable abſciſs; and $DE = y$, the correſponding double ordinate: alſo make $CF = d$, and let f repreſent the abſolute and ultimate force of a fibre at C, in the moment of rupture; then, ſince the force of each fibre is ſuppoſed to vary as its extenſion, or as its diſtance from F, we have $d : x :: f : \frac{fx}{d}$ = the force of a particle at H; and the number of particles acting at this diſtance being y, we ſhall have $\frac{fxy}{d}$ for the ſum of the forces of all the fibres in the line D E; but this force, acting upon the lever at the diſtance H F, its reſiſtance will be $\frac{fx^2y}{d}$; and hence the ſum of all the reſiſtances of every fibre in the ſection will be $= \int \frac{fyx^2\dot{x}}{d}$: now this is to be equal to the direct coheſion of all the fibres acting at ſome required diſtance F I; that is, $FI \times \int y\dot{x} \times f = \frac{f}{d} \times \int yx^2\dot{x}$, or $FI = \frac{1}{d}\,\frac{\int yx^2\dot{x}}{\int y\dot{x}}$: an expreſſion which is exactly equivalent to the general expreſſion $\frac{\int yx^2\dot{x}}{\int yx\dot{x}}$, for the centre of oſcillation of a body, multiplied by $\frac{\int yx\dot{x}}{\int y\dot{x}}$, the general expreſſion for the centre of gravity, divided by d. Hence, as theſe centres are known in moſt bodies which come under our conſideration in the preſent ſubject, it will be uſeful to avail ourſelves of them in determining what may properly be called the *centre of energy*, or *centre of tenſion.*

This being the caſe, both theories gave the ſame reſults, ſo far as related to the compariſon of the ſtrength of ſimilar beams, but of different dimenſions; thus, from both, it was ſhewn, that beams of the ſame depth and breadth were to each other, in point of ſtrength, inverſely as the length; that when the length and depth were the ſame, the ſtrength varied as the breadth; when the breadth and length were the ſame, the ſtrength was directly as the ſquare of the depths; deductions which have been found to agree very nearly with experiment. There were, however, ſome expreſſions ariſing out of theſe two hypotheſes which were totally irreconcileable with each other. In the firſt place, although the proportions were the ſame, the abſolute ſtrength in the one caſe, was to that in the other as 2 to 3, in rectangular beams; and in triangular beams, the diſagreement was ſtill more ſtriking: alſo, according to Galileo, the ſtrength of a triangular beam, with its edge upwards, was to the ſame with its baſe upwards, as 1 to 2; and, according to Leibnitz, as 1 to 3: whereas, as we have found from numerous experiments, it is ſtronger in the former poſition than in the latter, at leaſt in woods of ſome kinds, and probably in all.

Theſe anomalies led James Bernoulli to inveſtigate the queſtion *de novo.* This philoſopher obſerved, that at the inſtant a body is broken acroſs by a tranſverſe ſtrain, ſuch as we have all along ſuppoſed, a part of the fibres is in a ſtate of extenſion, as aſſumed by Leibnitz, and a part in a ſtate of compreſſion, a circumſtance which had not before been introduced into the conſideration of the queſtion: he moreover doubted of the propriety of the principle, *ut tenſio ſic vis*, employed by Leibnitz, and made ſome experiments, whereby he proved that this is not, at leaſt, a general principle; but the only effect of his obſervations and experiments went no farther than proving that Leibnitz's theory was inadmiſſible, for he ſubſtituted no other in its place, except ſo far as his theory of the elaſtic curve (a problem which grew out of the preſent queſtion) may be conſidered as applicable to this ſubject; had he purſued the idea he ſeems firſt to have promulgated, of a part of the fibres being compreſſed, and a part in a ſtate of tenſion, and conſequently that the line about which the beam turns is ſomewhere within the area of the ſection of fracture, we might have expected, from his extraordinary talents, a complete ſolution of this very intereſting problem; inſtead of which, he contented himſelf with ſtating a few general obſervations, and pointing out the difficulty of the determination of the neutral axis, or of that line which ſuffers neither compreſſion nor extenſion, which is the principal deſideratum for eſtabliſhing a correct theory; and in that ſtate he left the queſtion, and in that ſtate it has ever ſince remained.

The only other attempt, that we know of, at eſtabliſhing a new theory, is that given by Dr. Robiſon, under the article *Strength*, in the Encyclopædia Britannica. This

author has taken into his confideration the areas of compreffion and of extenfion; but for want of experiments, is unable to affign the pofition of the neutral axis: we fufpect, alfo, an important error in the principle which he has laid down, *viz.* that notwithftanding the beam really turns about what he properly calls a neutral axis, yet that in our inveftigation, we muft compute the effect of the rotation, as if it was made about the centre of compreffion. We were much ftruck with the fingularity of this affertion, and have, we believed, proved its fallacy in various experiments.

There is no doubt, from various experiments, and particularly from thofe of Du Hamel, when a piece of timber is fubmitted to the tranfverfe ftrain we are confidering, that only a part, and probably but a fmall part, of the whole number of fibres, has a tendency to refift the fracture by means of their tenfion, while the reft of the fibres act merely from their refiftance to compreffion. Du Hamel was, we believe, the firft author who demonftrated the fact by experiment. He took fixteen bars of willow, two feet long, and half an inch fquare, and fupporting them by props under their ends, he broke them by weights hung on their middle. Four of them broke with the weights 40, 41, 47, and 52 pounds, the mean of which is 45. He then cut four others of them through one-third of their depth on the upper fide, and filled up the cut with a thin flip of harder wood, ftuck in pretty tight. Thefe were broken with weights of 48, 54, 52, and 50 pounds, the mean of which is 51. He then cut four others half through, and thefe required 47, 49, 50, and 46 pounds to break them, the mean of which is 48; the remaining four were cut to two-thirds of their depth, and their mean ftrength was 42 pounds.

In another fet of his experiments we have the following refults, *viz.*

Six bars of willow 36 inches long, and $1\frac{1}{2}$ inch fquare, were broken at a medium with 525 lbs.

Six bars cut one-third through, and the faw-cut filled up with a flip of hard wood, and ftuck in tight, broke with 551 lbs. at a medium.

Six bars cut half through, and the cut filled up in the fame manner, bore 542 lbs. before the fracture; and

Six others cut three-fourths through, broke with 530 lbs.

A batten cut fimilarly to the latter, that is to fay, three-fourths through, when nearly broken, being unloaded, and a thicker flip put into the cut, in order to fill up the part which had been compreffed, fo as to bring the batten ftraight again, but without ftraining it, bore afterwards 577 lbs.

It will be remarked, that in thefe experiments the bars appear to have been ftronger after being cut one-third through, than when whole; and even when cut half through, they ftill bore more than when they were entire. This feems to have arifen from the faw-cut being filled up with a harder wood, which rendered the beam ftiffer than when in its natural ftate, by oppofing a greater refiftance to compreffion; and this may account for his beams being nearly as ftrong when cut three-fourths through, as when whole, as we have reafon to believe, that there are very few woods, if any, in which the neutral line lay fo near as within one-fourth of the bottom. We have made fimilar experiments on fir, and fome other kinds of wood; and found that three beams of fir, 30 inches long, 2 inches deep, and 1 inch thick, broke with 882 lbs. 871 lbs. 852 lbs. refpectively, the mean being 864 lbs. We then cut three other fimilar beams five-eighths through, and having filled up the cut with flips of pear-tree, found their ftrengths equal to 808 lbs. 846 lbs. and 835 lbs. of which the mean is 830 lbs.: thefe proved that the neutral line was nearer the bottom than three-eighths, becaufe the pear-tree wedges, being fofter than the fir, the deflection of the beams was throughout greater, which fhew that they had loft in ftiffnefs by the cutting; whereas Du Hamel's beams had gained ftiffnefs from the circumftance of being filled up with wood harder than themfelves: after all, however, this kind of experiment is not the beft calculated for detecting the pofition of the neutral axis.

From what has now been ftated, it is very obvious, that the theories both of Galileo and Leibnitz muft be extremely defective, fo far at leaft as they propofe them to be employed in afcertaining the abfolute ftrain that a beam will bear, when acted upon tranfverfely by any weight, whether as fupported at its ends, or by having one end fixed in a wall, as we have hitherto fuppofed. And as to the theory which Dr. Robifon has advanced in the place above referred to, although it doubtlefs approaches much nearer to the truth, it is ftill, we conceive, incomplete; firft, for want of experiments, from which alone the neutral axis can be determined; fecondly, becaufe he has not affigned the law of compreffion and tenfion, which is neceffary for determining thofe centres in the fection of fracture; and thirdly, becaufe (as we have before ftated) he fuppofes the rotation to be made about the centre of compreffion, inftead of its being made about the neutral axis, and affigning the whole refiftance to fracture to the extended fibres, inftead of confidering one half of it as due to compreffion and tenfion refpectively. It is true that this may make no difference in the refults, while we confine our inveftigation to rectangular beams, but it makes an important difference in triangular and other formed beams; in which cafes, although it agrees better with experiment than the theories of either Galileo or Leibnitz, it is ftill very defective, as it gives greater ftrength to beams of a certain form, and in certain pofitions, where experiment fhews them to be the weakeft.

We cannot fubmit any of the formulæ of this author to computation, as they are merely general fymbols, in which the indeterminate letters are to be fupplied by numbers drawn from experiments; but in the two former, the expreffions are determinate, and they may therefore be fubmitted to calculation, and the refults compared with thofe that have been drawn from actual experiment; but before we proceed to this comparifon, it will be proper to confider the relative ftrains that a beam is fubject to, according to the manner in which it is fupported; a confideration that is independent of any particular theory of refiftances, and one in which different authors have come to very contradictory conclufions.

1. A beam having one end firmly fixed in a folid wall, will bear the fame weight at its extreme end, as if the beam paffed through the wall to the fame length, and was loaded by an equal weight at its other end; its bearing in the wall being in the latter cafe fuppofed to be reduced theoretically to a line, and practically to fuch a bearing as will not damage the beam by cutting it. *Fig.* 6.

This will be evident to fuch of our readers who are converfant with the laws of motion, and who are familiar with the idea, that "action and re-action are equal and contrary;" but to others it may not be amifs to offer a few obfervations, by way of illuftration.

Let A P C, and A′ P′ C′, (*fig.* 7.) be two detached levers, fupported on the props P, P′; and let us fuppofe their ends at C, C′, to be held towards each other by a rope or cord

C C′. Now if we ſuppoſe the lever A′ P′ C′ to be fixed by any means to the poſition ſhewn in the figure, while the other lever, A P C, is loaded with the weight W, and free to turn about P, the cord or fibre C C′ will be ſtretched exactly in the ſame manner as the fibre at C (*fig.* 6.), when the beam is faſtened ſolidly in the wall; and if, inſtead of ſuppoſing the firſt lever, A′ P′ C′, to be fixed, we now ſuppoſe it loaded with a weight $W' = W$, and free to turn about P′; then the fibre C C′ will be in all reſpects circumſtanced like the fibre at C (*fig.* 6.), when the beam is ſuppoſed to paſs through the wall, and a weight $W' = W$, acting in the direction $A' I = A I$.

But it is obvious that in *fig.* 7. the tenſion of the cord or fibre is the ſame in both caſes; the only difference being, that the re-action of the fixed lever A′ P′ C′, in the firſt inſtance, (and which is exactly equivalent to the force or energy of the weight W,) is, in the ſecond, ſupplied by the action of an equal weight acting at an equal diſtance P′ A′; and, conſequently, whatever weight acting at the extremity is found ſufficient to break a beam when firmly fixed in a wall, it will require an equal weight hung on at each end of a ſimilar beam of double length, when reſting on a prop in the middle, to produce the fracture.

2. And hence again it follows, that whatever weight will be juſt ſufficient to break a beam when fixed ſolidly in a wall, a double weight will be required acting in the middle point, of a ſimilar beam, of double length, ſupported on two props, as in *fig.* 8: for it will be exactly the ſame as to the mechanical action, whether we conſider the weight as acting at E, and the beam turning about P and P′, or whether we ſuppoſe a fulcrum at E, and the beam turning about that point by means of weights W′, W″, paſſing over the pullies Q, Q, and each equal to half the centre-weight W, and the latter is evidently the ſame as the action of the weights W, W′, *fig.* 6, only that they are acting in an oppoſite direction.

3. When a beam is loaded on any other point than its centre, and having its extremities reſting on props, the ſtrain upon it will be as the rectangle of the two unequal parts, and therefore the ſtrain will be the greateſt, or the ſtrength of the beam the leaſt, when the weight acts at its centre.

For let the weight W preſs upon the beam at C (*fig.* 9.) then is the weight equal to the preſſures upon A and B; and the preſſure upon $A = \frac{W \times BC}{AB}$, while the preſſure upon $B = \frac{W \times AC}{AB}$; but the re-action of either point of ſupport is equal to the preſſure upon it, and this may be conſidered as a force acting at the point C, as upon the arm of a lever; ſo that the ſtreſs at C, is as the preſſure at either point of ſupport into its diſtance from C, that is, the preſſure is as $\frac{W \times BC}{AB} \times AC$, or as $\frac{W \times AC}{AB} \times BC$, which are manifeſtly equal the one to the other; but as W, and A B, are given, the ſtreſs varies as the rectangle; or if we ſuppoſe the ultimate ſtrength of fibre the ſame, then W will vary inverſely as the rectangle; and as the rectangle is the greateſt when the parts are equal, therefore in the ſame caſe the ſtrength of the beam will be the leaſt.

The ſame thing will obtain, if the weight be equally diffuſed through the whole of the beam; for in this caſe, as in the former, the ſum of the preſſures upon A and B will be equal to the whole weight; and if w be the weight of the part B C, its preſſure upon A will be $\frac{w \times \frac{1}{2} BC}{AB}$, and this referred back to the point C, will give $\frac{w \times \frac{1}{2} BC}{AB} \times AC$ for the ſtreſs, which therefore varies as the rectangle $BC \times AC$, as before.

4. When a beam is firmly fixed at both ends, as in two walls, or otherwiſe, the weight neceſſary to break it will be double of that which would produce the fracture if the ends were only ſupported.

Let A B C D (*fig.* 10.) repreſent a beam firmly fixed at each end, which is to be broke by a weight hanging upon its centre-point, as at E. Now, firſt let us ſuppoſe the beam cut through at E, ſo as to offer no reſiſtance, and ſuppoſe the weight to be hung on ſo as to act equally upon the arms D E, C E, then W muſt be equal to double that which would break one part, as is obvious; and this is the ſame as would break the whole beam, when only ſupported at its ends by one prop, conſequently when the beam is whole in the ſection E F, beſides the weight W, which we have ſeen is neceſſary to overcome the reſiſtances at D and C, an equal weight, W, muſt be added to overcome the equal reſiſtance in the ſection E F; therefore the whole weight is equal to double that which would break the beam when only looſely ſupported at its two ends.

5. When a beam is fixed with one end in a wall, at any given oblique angle, the weight neceſſary to produce the rupture, is to the weight which would break the beam, if fixed horizontally, as radius to the coſine of the angle.

Let A B C D (*fig.* 11.) repreſent a beam fixed in a wall at the angle ſhewn in the figure; let D I be the vertical direction of the weight, and let this weight be repreſented by the line D I, and reſolve this into the two forces D B and B I, the former perpendicular, and the other parallel to the beam A B; then it is obvious, that D B only will denote that part of the weight which is effective in producing the fracture, and that a weight which is to W, as D B is to D I, would break the beam when placed horizontally; therefore converſely, the weight neceſſary to break the beam in this poſition, is to that which would break it when fixed horizontally, as D I to D B; or as radius to the coſine of the angle of inclination of the beam to the horizon.

Moſt authors, indeed all we have ever read, make the ſtrength in this caſe as the ſquare of the radius to the ſquare of the coſine; becauſe the area of fracture is greater in the proportion of radius to coſine, which blended with the mechanical effect of the lever, gives rad.^{2} : coſ.^{2}; but the reſult of experiment by no means juſtifies ſuch an hypotheſis, nor does a phyſical conſideration of the ſubject render it neceſſary, the number of fibres being the ſame in both caſes.

We may now bring under one point of view the deductions drawn from the preceding propoſitions; *viz.*

1. The ſtrength of a beam fixed with one end in a wall, and loaded at the other end, is to the ſtrength of a beam of the ſame length, ſupported on two props, and loaded in the middle, as 1 to 4; or to a beam of double the length, loaded in the middle, as 1 to 2.

2. The ſtreſs upon a beam, ariſing from the ſame weight placed at different points, is as the rectangle of the two parts; and, therefore, the ſtrength of the beam, or its reſiſtance to fracture, will be inverſely as the ſame rectangle; and,

consequently, the stress is the greatest, or the strength the least, when the load is placed in the centre.

3. The resistance to fracture in a beam *supported only* at its extremes, is to the resistance of the same when *fixed* at both ends, as 1 to 2.

4. The stress upon a beam, arising from any oblique action upon it, is as that force into the cosine of the angle; or the resistance will be in this case as radius to the cosine. These results are all independent of any particular theory of resistance, or rather, they form a part of every one; but they require certain modifications when applied to the determination of the absolute strength of beams. While they are merely used for ascertaining the proportional strengths, for the purposes of building, machinery, &c. they may be properly employed in the forms above given; it will be proper, however, to point out a few of the modifications to which we have alluded, as it will tend to clear up some apparent anomalies which have arisen in the experiments of M. Buffon, Belidor, Parent, Petit, &c.

In the first place, then, it will have been observed, that all our deductions have been made upon the supposition, that the beam preserves its rectilinear form and original position; and no account whatever has been taken of the deflection which it experiences from the horizontal or oblique line in which it is first supposed to be placed; nor is it necessary to attend to this circumstance while our views are carried no farther than determining the proper dimensions of timbers, in buildings, mechanical constructions, &c. because these are never submitted to strains that cause any important deflections; but when we attempt to reconcile theory with the result of experiments in which the beams are absolutely fractured, we must no longer omit the introduction of these particulars into our investigations.

Instead, therefore, of supposing a beam fixed at one end in a wall, and loaded at the other, to retain its horizontal position, as in *fig.* 6, we must consider it as being very considerably deflected out of that position, as in *fig.* 12; and if we here, for the sake of perspicuity, represent the resistance of the fibres to fracture by a weight P, it will be obvious that, in order that P and W may be in equilibrio, the weight W must be to the weight P, not simply in the inverse ratio of the arms A I, A C, but as these distances into the sines of their respective angles of directions; that is, as $A\,I \times \text{sin.}\ A\,I\,I' : A\,C\ \text{sin.}\ A\,C\,Q :: P : \dfrac{A\,C \times P}{A\,I \times \text{sin.}\ A\,I'\,I'} = W$ (because $\text{sin.}\ A\,C\,Q = 1$); whereas our former result was $\dfrac{A\,C \times P}{A\,I}$; the weight therefore required to break a beam in this position, is greater than what we found it to be in the case where no deflection was considered, in the ratio of the cosine of the angle of deflection to radius.

This is sometimes a very important quantity, as we have seen beams of three feet length, and two inches square, deflected twelve or thirteen inches, that is to say, to the amount of one-third of their length, or 20°: and the cosine of 20° is to radius as 93 to 100.

The reverse of this happens when a beam is loaded in the middle, and supported at its extremities on two props; for in this case the re-action of the props is not made, as we have supposed, in a direction opposite to the vertical action of the weight, but perpendicular to the arms of the lever. The beam A B C D (*fig.* 13.) is therefore kept in equilibrio with regard to its strain, by the action of three forces, *viz.* the weight W, the quantity and direction of which may be denoted by the diagonal S G, *viz.* the diagonal of the parallelogram, of which P S, P S, are two adjacent sides, and which equally denote the quantity and direction of the re-action of the props: which will therefore be greater than $\frac{1}{2}$ W, the quantity we have supposed in our former investigation, in the ratio of S P' to S F; that is, in the ratio of radius to the cosine of the angle of deflection.

Hence it appears that when a beam is fixed at one end, and the computed weight necessary to break it be W, the real weight that must be employed will be $\dfrac{W}{\text{cos.}\ D}$; D denoting the angle of deflection: but when the beam is supported at both ends, and the computed weight W', and the angle of deflection D', then the real weight will be W' cos. D'.

Hence, supposing the former beam to have the same breadth and depth, but only half the length of the latter; we shall have, according to the preceding theory, $W : W' :: 1 : 2$, whereas, from this modification of it, the analogy is $W : W :: 1 : 2\ \text{cos.}\ D\ .\ \text{cos.}\ D'$, which (if the beams are small in proportion to their length, as was the case with those of M. Parent) is quite sufficient for reducing the ratio to 2 : 3 or 4 : 6, as found by that author.

Again, with regard to a beam having its two ends solidly fixed, its strength, according to our preceding investigation, as compared with an equal beam supported at both ends, is as 2 : 1; but this supposes the three fractures to take place at the same time, or that the same deflection that is necessary for producing the fracture at F (*fig.* 10.) will also at the same time cause the fracture to happen in the two sections D A, C B; but this, like the preceding, will not apply to the ultimate result; as the deflection of the half beams A F, B F, is found in experiment to be nearly double that of the whole beam A B; and therefore, supposing the deflection to be as the weight, as it is in fact very nearly for a considerable time, it will only require, in addition to the weight that would break the beam, when supported at its ends, such a weight as would produce the deflection in the half beams, equal to that at which the supported beam breaks; that is, about half the said weight; and, consequently, the ratio of the strength of the fixed beam to that which is merely supported, instead of being as 2 to 1, will be reduced to that of 3 to 2, or 9 to 6, as found in the experiments above referred to, as well as in those of Belidor, as published by him in his "Science des Ingenieurs." M. Parent found that a beam supported at one end only in a wall, and another of double length *supported* at both ends, and an equal beam *fixed* at both ends, broke with weights which had very nearly the proportion of 4, 6, and 9; whereas the theory, which takes no account of deflection, gives 4, 8, 16; but what is stated above, shews that Parent's numbers are those which ought to be found by experiment; and the same explanation renders the results in the following table of Belidor also perfectly reconcileable with each other.

We have also, since the above was written, made several experiments of the same kind, in order to compare the strength of beams according to the manner in which they were supported or fixed, at one end or both; and according as they were fixed horizontally, or at different angles of inclination; and in all those cases the results answer very nearly to what the preceding theory requires. Thus a beam of fir six feet long and two inches square, supported at each end, broke with 744 lbs.; and the mean of several experiments on similar pieces of the same dimension fixed at each end, require 1105 lbs.; and the fragments of the same, three feet long, broke with one end in a wall, required at a medium 400 lbs.; the ratio of which numbers are not very different from those above stated.

Belidor's Experiments.—Theſe pieces were found even-grained oak; the column *b* contains the breadth, *d* the depth, and *l* the length, all in inches: *p* ſhews the number of pounds which broke them, and *m* the mean weight, alſo in pounds.

N°	*b*	*d*	*l*	*p*	*m*	How fixed.
1	1	1	18	400 415 405	406	the ends lying looſe.
2	1	1	18	600 600 624	608	the ends firmly fixed.
3	2	1	18	810 795 812	805	the ends looſe.
4	1	2	18	1570 1580 1590	1580	the ends looſe.
5	1	1	36	185 195 180	187	the ends looſe.
6	1	1	36	285 280 285	283	the ends fixed.
7	2	2	36	1550 1620 1585	1585	the ends looſe.
8	$1\frac{2}{3}$	$2\frac{1}{3}$	36	1665 1675 1640	1660	the ends looſe.

By a compariſon of theſe reſults, we find

1. From a compariſon of experiments 1 and 3, *that the ſtrength is proportional to the breadth.*

2. Experiments 3 and 4 ſhew *that the ſtrength is proportional to the ſquare of the depth.*

3. Experiments 1 and 5 ſhew *the ſtrength to be nearly in the inverſe ratio of the length.*

4. Experiments 5 and 7 ſhew *the ſtrength proportional to the breadth and ſquare of the depth.*

5. Experiments 1 and 7 ſhew, by combination, *that the ſtrength is in the ratio of the area of fracture into the depth, and in the inverſe ratio of the lengths.*

6. Experiments 1 and 2, as alſo 5 and 6, ſhew *that the ſtrength of beams fixed at both ends is to that of thoſe which are only ſupported in the ratio of* 3 : 2.

ave ſhewn that this laſt proportion is about what ought to reſult from experiments; although no theory that we know of introduces this conſideration.

Another diſcrepancy between theory and experiment is, where the ſtrength ought to be inverſely as the length, it ſhews itſelf in the above experiments, but is very remarkable in thoſe of M. Buffon; and though our preceding remarks will explain very ſatisfactorily this deviation, we are almoſt afraid to offer it as an illuſtration; after ſeeing it treated as an inexplicable paradox by ſome writers of the firſt eminence: Dr. Robiſon, for example, ſays, "the engineer will carefully keep in mind the important fact, that a beam of quadruple length, inſtead of having $\frac{1}{4}$th of the ſtrength, has only about $\frac{1}{6}$th; and the philoſopher ſhould endeavour to diſcover the cauſe of this diminution, that he may give the artiſt a more accurate rule of computation."

In another place he attempts to account for it from phyſical conſiderations, *viz.* that the trees being ſtrongeſt at the root end: Buffon's longeſt pieces were broke in the weakeſt part, which however does not appear quite certain, as we cannot tell from which end his ſhorteſt pieces were cut; he alſo thinks, that the curvature being greateſt in the longer pieces, may alſo be a cauſe of the deficiency above alluded to. We are not diſpoſed to deny that theſe may both have an influence; but it certainly appears to us, that inſtead of looking for a phyſical explanation, what we have before remarked with regard to the deflection is quite ſufficient to account for the anomaly on pure mathematical principles. We have ſeen, that if W be the computed weight, independent of deflection, the abſolute weight will be W coſ. D, D being the angle of deflection; and as this deflection, both from theory and practice, is found to increaſe as the ſquare of the length; it follows, that when the length is quadrupled, the depth of deflection will be ſixteen times greater; that is, the ſine of the angle of deflection will be ſixteen times more in one caſe than in the other, while the radius will be only four times longer; and therefore, the angle is in one caſe about four times what it is in the other, (ſuppoſing in a rough way the angle to vary as the ſine). Conſequently, if W × coſ. D is the weight which breaks the ſhorter beam, $\frac{1}{4}$ W × coſ. 4 D ought to be that which breaks the longer one; and this we preſume will nearly, if not entirely, account for the decreaſe of ſtrength in Buffon's experiments. We cannot perceive but that this reaſoning is perfectly legitimate, yet we are aſtoniſhed that it ſhould not have occurred to ſo keen a mathematician as the one to whom we have alluded, or to ſome one of the writers on this ſubject, and on this account we offer it with ſome heſitation.

The following table contains the reſult of Buffon's experiments, which are by far the moſt valuable of any that have yet been made, both on account of the number of them, and the ſize of the beams that were employed. The dimenſions are given in metres, and the weights in kilograms, as reduced by M. Girard, except that we have not always retained the ſame number of decimals; theſe may be reduced to Engliſh meaſure by obſerving, that 1 metre = 3.281 Engliſh feet, and 1 kilogram = 2.20652 lbs. avoirdupois.

TABLE of Buffon's Experiments on the Strength of Square Oak-beams, fupported at both Ends.

No. of Experiments.	Side of the Square.	Length of the Piece.	Weight of the Piece.	Weight which it bore before it broke.	Deflection before the Fracture.	Time from the firft Fracture to the final Rupture.	Deflection at the inftant of Rupture.	Lengthening or ftretching of the Fibres to a Metre in Length.	Mean ftretching of the Fibres.
	Metres.	Metres.	Kilog.	Kilog.	Metres.	Hours.	Metres.	Metres.	Metres.
1	0.1082	2.2732	29.34	2616	0.0946	0.2013	0.1217	0.005	
2		2.2732	27.39	2580	0.1217	0.1527	0.1758	0.011	
3		2.5979	33.26	2250	0.1013	0.1041	0.2164	0.013	
4		2.5979	30.81	2201	0.1262	0.0902	0.2976	0.026	
5		2.9227	37.66	2005	0.1307	0.0972	0.2029	0.009	
6		2.9227	34.72	1932	0.1488	0.0833	0.2435	0.013	
7		3.2473	41.08	1773	0.1578	0.1041	0.1758	0.005	
8		3.2773	40.10	1760	0.1758	0.1041	0.1758	0.004	
9		3.8969	48.91	1491	0.1894		0.1894	0.004	
10		3.8969	47.93	1430	0.1894		0.2164	0.006	
11	0.1353	2.2732	45.97	5759	0.0676	0.4027	0.0968	0.003	
12		2.2732	43.33	5515	0.0676	0.3819			
13		2.5979	50.87	4842	0.0721	0.2777	0.1353	0.005	
14		2.5979	49.89	4732	0.0789	0.2708	0.1239	0.004	
15		2.9227	57.71	4108	0.0811	0.1944	0.1623	0.006	
16		2.9227	56.74	4072	0.0878	0.1944	0.1443	0.004	
17		2.9227	56.25	4010	0.0946	0.1805	0.1353	0.004	
18		3.2473	64.56	3534	0.0856	0.1458	0.2029	0.007	
19		3.2473	63.59	3448	0.0946	0.1388	0.1825	0.006	
20		3.2473	62.85	3472	0.1082	0.1944	0.2321	0.010	
21		3.8969	76.30	2959	0.1488	0.2083	0.3517	0.016	0.0074452
22		3.8969	75.32	2983	0.1556				
23		4.5464	87.06	2641	0.2164		0.2706	0.007	
24		4.5464	86.08	2543	0.2231	0.1250	0.3517	0.011	
25		5.1959	102.23	2164	0.2186	0.1180	0.4328	0.013	
26		5.1959	100.27	2091	0.2209	0.1041	0.4906	0.017	
27		5.8453	113.48	1834	0.2164	0.0763	0.4599	0.012	
28		5.8453	112.99	1499	0.2209	0.0694	0.4058	0.009	
29		6.4946	129.64	1601	0.2389	0.0694	0.4373	0.009	
30		6.4946	126.68	1553	0.2706	0.0555	0.5547	0.014	
31		7.1440	137.45	1455	0.3043	0.1250	0.5141	0.010	
32		7.7939	151.63	1076	0.2976	0.1111	0.4058	0.005	
33		7.7939	150.16	1039	0.3652	0.1041	0.4328	0.006	
34		9.0928	178.04	880	0.4870	0.1180	0.6768	0.011	
35		9.0928	166.09	885	0.5952	0.1180	0.7576	0.013	
36	0.1624	2.2732	62.8551	9416					
37		2.2732	58.9373	9122					
38		2.5979	72.8827	7679	0.0631	0.7568	0.1353	0.005	
39		2.5979	71.4152	7508	0.0653	0.6804	0.1127	0.011	
40		2.9227	81.1982	6579	0.0676	0.4999	0.1398	0.013	

TABLE — *continued.*

No. of Experiments.	Side of the Square.	Length of the Piece.	Weight of the Piece.	Weight which it bore before it broke.	Deflection before the Fracture.	Time from the first Fracture to the final Rupture.	Deflection at the instant of Rupture.	Lengthening or stretching of the Fibres to a Metre in Length.	Mean stretching of the Fibres.
	Metres.	Metres.	Kilog.	Kilog.	Metres	Hours.	Metres.	Metres.	Metres.
41	0.1624	2.9227	80.4644	6285	0.0766	0.3541	0.1353	0.026	
42		3.2473	91.9594	5612	0.0811	0.3194	0.2164	0.008	
43		3.2473	90.9911	5392	0.0946	0.3055	0.1623	0.004	
44		3.8969	109.5689	4500	0.1082	0.2152	0.1894	0.004	
45		3.8969	108.1012	4402	0.1107	0.2222	0.1578	0.003	
46	0.1624	4.5464	124.7322	3644	0.1217	0.1736	0.2706	0.007	
47		4.5464	124.2431	3668	0.1107	0.1527	0.3066	0.009	
48		5.1959	143.8087	3057	0.1188	0.1388	0.2164	0.003	
49		5.1959	143.3197	3167	0.1578	0.1319	0.2706	0.005	
50		5.8453	163.3747	2751	0.2006	0.1111	0.5952	0.020	
51		5.8453	161.9073	2690	0.2299	0.0972	0.2706	0.004	
52		6.4946	184.4080	2457	0.2570	0.0833	0.5600	0.014	
53		6.4946	183.4297	2384	0.2389	0.0763	0.3788	0.006	
54	0.1894	2.5979	99.78	12791	0.0743	0.8749	0.1082	0.003	
55		2.5979	99.78	12693	0.0676	0.9235	0.1013	0.003	
56		2.9226	111.03	11152	0.0836	0.6943	0.1488	0.005	
57		2.9226	110.05	10712	0.0789	0.6735	0.1398	0.004	
58		3.2473	124.24	9611	0.0689	0.5068	0.3519	0.023	
59		3.2473	123.25	9440	0.0811	0.5277	0.2435	0.011	
60		3.8969	147.72	8217	0.0789	0.4374	0.2029	0.005	
61		3.8969	147.23	7606	0.0900	0.4166	0.1894	0.004	0.0074452
62		4.5464	173.64	6652	0.1127	0.3816	0.1961	0.003	
63		4.5464	171.69	6285	0.1013	0.3333	0.2186	0.004	
64		5.1959	198.59	5429	0.1307	0.2847	0.2706	0.005	
65		5.1959	197.12	5331	0.1420	0.2500	0.3088	0.007	
66		5.8453	222.07	4622	0.1488	0.1875	0.3246	0.006	
67		5.8453	222.07	4597	0.1578	0.1527	0.2570	0.003	
68		6.4946	247.01	4182	0.2119	0.1041	0.3403	0.005	
69		6.4946	247.50	3913	0.2299	0.0902	0.3246	0.004	
70	0.2165	3.2473	161.90	13598	0.0811	0.1805	0.1555	0.004	
71		3.2473	161.90	13047	0.0608	0.2360	0.1194	0.002	
72		3.8968	194.19	11190	0.0811	0.6249	0.1660	0.003	
73		3.8968	193.45	10750	0.0789	0.5763	0.1803	0.004	
74		4.5464	225.49	9807	0.1036	0.4582	0.2299	0.005	
75		4.5464	224.51	9538	0.0856	0.4304	0.2164	0.004	
76		5.1959	256.80	8217	0.1398	0.3263	0.2706	0.005	
77		5.1959	256.31	7801	0.1013	0.3472	0.2016	0.005	
78		5.8453	290.55	6603	0.1217	0.2222	0.2751	0.004	
79		5.8453	290.06	6309	0.1104	0.2083	0.2096	0.002	
80		6.4946	323.79	5759	0.1758	0.1666	0.2976	0.004	
81		6.4946	322.83	5967	0.1623	0.1944	0.2605	0.002	

It remains now for us to offer a few obſervations with regard to the relation between the ſtrength of direct cohesion, and the ſtrength of beams ſubmitted to tranſverſe ſtrains; but, unfortunately, we have very little on which to reſt any theory in this reſpect. We know of no experiments that have yet been made with a view to this determination, except thoſe to which we have above referred, as being at preſent in progreſs at the Royal Military Academy, and theſe are not yet ſufficiently forward to enable us to offer any decided theory.

According to Galileo's theory, if f denote the ſtrength of direct coheſion, that is, the number of pounds neceſſary to break a bar of one inch ſquare; a the area, in inches, of the ſection of fracture; d the depth of its centre of gravity from the edge about which the beam is ſuppoſed to turn; and l the length, alſo in inches; and W the required weight; then

1. *When the beam is fixed with one end in a wall,*

$$W = \frac{fad}{l}.$$

2. *When the beam is ſupported at both ends, then*

$$W = \frac{4fad}{l}$$

3. *When the beam is fixed at both ends,*

$$W = \frac{8fad}{l}.$$

The weight in both the latter caſes being ſuppoſed to reſt on the middle of the beam, and in the firſt at its end. When the weight acts at any other part of the beam, the ſtreſs varies directly as the rectangle of the two parts, or the ſtrength is inverſely as the ſame.

According to Leibnitz's theory, if a is the area, l the length in inches, and f the ſtrength of direct coheſion in pounds, on a ſquare inch, as before; alſo D the depth of the ſection of fracture, Δ the diſtance of its centre of oſcillation, and d that of its centre of gravity from the point about which the beam turns; then,

1. *When the beam is fixed at one end,*

$$W = \frac{fa\Delta d}{lD}.$$

2. *When the beam is ſupported at both ends,*

$$W = \frac{4fa\Delta d}{lD}.$$

3. *When the beam is fixed at both ends,*

$$W = \frac{8fa\Delta d}{lD}.$$

From theſe general theorems it is uſual to draw a variety of corollaries as to the ſtrength of beams of different forms, and in different poſitions. Thus, from the former, it appears that a triangular beam, fixed with one end in a wall, with its *edge* downwards, or ſupported at its two ends, with its *baſe* downwards, has *double* the ſtrength of an equal beam laid the contrary way, *i. e.* with its baſe down in the firſt caſe, and upwards in the ſecond; and Leibnitz's formula makes the ſtrength *three times* as much; whereas experiment proves that the beam is weaker in both theſe caſes, where, according to their theory, it ſhould be ſo much ſtronger.

Similar erroneous concluſions are alſo drawn from theſe theorems, with regard to hollow cylinders, not bored through the axis, but on one ſide of it; the ſtrength, according to the above, being greateſt when the beam is made to turn about the thinneſt part: but here, again, experiment ſhews it to be weakeſt in that poſition.

With regard to the hollow cylinder bored through its axis, the above theorems, though they are ſtill inaccurate with regard to the proportion between the direct coheſion and the tranſverſe ſtrain, are not much out in reſpect to the proportional ſtrength, according to the ſize of the bore, and the thickneſs of the ſides: in fact, both ſets of theorems give the ſame reſults, with regard to the proportional ſtrengths, as depending upon the lengths, depths, breadths, &c. of the beams, while theſe remain of the ſame form, and reſt in the ſame poſition; it is in the compariſon of different formed beams with each other, or different poſitions of the ſame beam, where the defect is the moſt obvious; and particularly with regard to *all beams*, as depending upon the ſtrength of direct coheſion. On this account, we ſhall diſpenſe with the corollaries and deductions above referred to, as being more likely to miſlead than to inſtruct the engineer, although we thought it right to mention them; and if we cannot ſupply them with well eſtabliſhed rules and formulæ, we will at leaſt endeavour to point out how ſuch may be obtained.

We have already ſtated that the beam, inſtead of turning about the line C D (*fig.* 1.), as ſuppoſed by Galileo and Leibnitz, really turns about a line within the area of fracture, as ſhewn by the ſection, *fig.* 5; *viz.* inſtead of turning about the lower point C, the beam will turn about ſome other line, repreſented in the figure by n, the ſituation of which is unknown, but whoſe poſition is abſolutely neceſſary to be determined, in order to eſtabliſh a correct theory of the ſtrength of beams. According to Du Hamel's experiments on willow, it is at about one-third the depth from A; and thoſe that we have made, make it about the ſame for fir: and though there may be ſome difference in this reſpect, in woods of different kinds, it is probably not far from that point in any.

Now all the fibres between n and A are thoſe only which are in a ſtate of tenſion; the others between n and C being in a ſtate of compreſſion; while the fibres in the line, of which the ſection is n, will be neither compreſſed nor ſtretched; on which account this is commonly called the *neutral line*, or *neutral axis*. Hence we ſee, that in the theories of Galileo and Leibnitz, the ſtrength of beams, as deduced from the ſtrength of direct coheſion, muſt far exceed the real ſtrength, not more than one-third of the fibres, which they ſuppoſe, being employed to reſiſt the fracture at leaſt by tenſion; alſo the centre of tenſion being at only one-third of the diſtance they have aſſumed, theſe combined would make the real ſtrength only one-ninth of the computed ſtrength. But as we may ſuppoſe that exactly one-half of the entire force is employed in producing the compreſſion, that is, that the beam turns about that point where the reſiſtance to compreſſion is equal to that of tenſion, this reduces it to $4\frac{1}{2}$ times; that is, the computed ſtrength is about $4\frac{1}{2}$ times greater than it would be, if the neutral line were, as we have ſuppoſed, at one-third of the depth from the upper ſurface of the beam.

This defect is common to both theſe authors, after conceding to each his own particular law of tenſion; that is to ſay, to Galileo, that every fibre acts with the ſame energy; and to Leibnitz, that the tenſion is as the force. But one or both of theſe ſuppoſitions muſt be erroneous; and we muſt ſay, that, independent of experiments, we ſhould certainly have been inclined to adopt the latter; but we are convinced, from a great multiplicity of reſults, that Galileo is much nearer, if not exactly conformable to the actual

operation. However difficult it, therefore, may be to account for this equality in the force of tenfion on phyfical principles, we muft adopt it as a fact deduced from experiment, and leave to the philofopher the explanation of its exiftence.

Our limits will not admit of reporting here the nature of the experiments, nor the calculations founded upon them, which led to this determination; but we hope foon to fee them laid before the public in another form. We can only give here the refult, which, as far as it is at prefent afcertained, is as follows:

The centre of tenfion and centre of compreffion are nearly or exactly coincident with the centre of gravity; and the neutral line, whatever may be the figure of the fection, is fo pofited, that the rectangle of the area of tenfion into the diftance of its centre of gravity from the faid line, is to the rectangle of the area of compreffion into the diftance of its centre of gravity as 1 *to* 3.

From which theorem, the neutral line for any formed beam may be determined, and the abfolute ftrength may then be found as follows, *viz.*: Let d denote the diftance of the centre of tenfion from the neutral line, a the area of tenfion, and l the length of the beam, all in inches; D the angle of deflection, and f the ftrength of direct cohefion on a fquare inch; then, without confidering the increafed length of lever,

1. *When the beam is fixed at one end,*

$$W = \frac{2fad}{l\,.\,\text{cof. D}}.$$

2. *When the beam is fupported at both ends,*

$$W = \frac{8fad}{l} \times \text{cof. D}.$$

3. *When the beam is fixed at both ends,*

$$W = \frac{12fad}{l} \quad \text{cof. D}.$$

And when the beam is fixed at one end at any angle, formula (1) will ftill apply; only increafing or decreafing the angle of deflection by the quantity of the firft angle of inclination, according as that inclination is downwards or upwards.

And when the beam is fupported, or fixed, at both ends, and either refting obliquely, or acted upon by an oblique force; the two latter formulæ become,

4. *For the beam fupported at each end,*

$$W = \frac{8fad}{l} \times \frac{\text{cof. D}}{\text{cof. I}}.$$

5. *For the beam fixed at each end,*

$$W = \frac{12fad}{l} \times \frac{\text{cof. D}}{\text{cof. I}}.$$

Where I denotes the angle which the direction of the force makes with the direction of the beam.

Note 1. It fhould be obferved that the preceding theorem, for determining the neutral line, is principally drawn from experiments on fir-beams. A different ratio than 1 : 3 may be neceffary in other kinds of wood; but at prefent that ratio has not been found.

Note 2. The deflection D, as we have before obferved, is not a neceffary datum in eftimating the ftrength of timber, for any practical purpofes of building, &c.: it is merely introduced in order to reconcile theory with the refult of experiments made upon the abfolute and ultimate ftrength; in which cafes, particularly in long beams, it becomes an important quantity, and muft not be omitted; and in all cafes where it is required, it muft be drawn from fome prior experiment on the fame kind of wood, by means of the following theorem, *viz.*

Let l, d, and D, reprefent the length, depth, and deflection of any beam; and l' and d' the length and depth of any other beam, whofe deflection D$'$ is required; then,

$$D' = \frac{l'^2 d D}{l^2 d'}.$$

See the feveral works referred to in the beginning of the article, by Bernoulli, Euler, Lagrange, &c.

We fhall now illuftrate thefe theorems by a few examples

Example 1.—The ftrength of direct cohefion on a fquare inch of fir being 13,000 lbs., required the weight neceffary to break a rectangular bar 30 inches long, 2 inches deep, and 1 inch in breadth; when fixed at one end in a wall, and the weight acting at the other; the deflection, computed from other experiments, having been found to be 5 inches.

Firft, to find the neutral line: here, fince the fection is a rectangle, the centres of tenfion and compreffion are each on the centres of their refpective areas; therefore, call the depth of tenfion x, the depth of compreffion will be $2 - x$, which alfo denote thefe areas; and we muft have, therefore,

$$\frac{x^2}{2} : \frac{(2-x)^2}{2} :: 1 : 3;$$

$$\text{or } 3x^2 = 4 - 4x + x^2; \text{ or } x^2 + 2x = 2.$$

$$\text{Whence } x = -1 + \sqrt{3} = .732 = a;$$

$$\text{alfo } \frac{.732}{2} = .366 = d;$$

$$\text{tan. of deflection} = \frac{5}{30} = \quad = .16666666.$$

Whence the angle D = 9° 34$'$, and its cofine = .9860; therefore, by formula 1,

$$W = \frac{2fad}{l\,.\,\text{cof. D}} = \frac{2 \times 13000 \times .732 \times .366}{30 \times .986} = 235\,\text{lbs.}$$

Example 2.—Required the weight that would break the fame beam when fupported at each end, rejecting the deflection, which is very inconfiderable.

By formula 2,

$$W = \frac{8fad}{l} = \frac{8 \times 13000 \times .732 \times .366}{30} = 928\,\text{lbs.}$$

Example 3.—Required the weight that would break the fame beam fixed at each end.

Rejecting the deflection, we have from formula 3,

$$W = \frac{12fad}{l} = \frac{12 \times 13000 \times .732 \times .366}{30} = 1492\,\text{lbs.}$$

Note.—We have here affumed 13000 for the force of direct cohefion; this, however, rather exceeds the greateft ftrength of fir, which varies from 10000 to about 13000 lbs.

Example 4.—Affuming the direct cohefion at 13000, and the fpecific gravity of fir 720; how long muft a beam be that is two inches deep, and one inch broad, which, fixed with one end in a wall, will juft break with its own weight?

Let x be the required length of the beam, in inches; its

weight will be $\frac{2x \times 720}{1728}$ ounces, or $\frac{90x}{1728} = \frac{5x}{96}$ pounds; and this weight will have the fame effect as if it acted all at one point in the centre of the beam, or at the diftance $\frac{1}{2}x$.

Hence, by fubftituting $\frac{5x}{96}$ for W in formula 1, we have

$$\frac{5x}{96} = \frac{2 \times 13000 \times .732 \times .366}{\frac{1}{2}x},$$

or $5x^2 = 192 \times 2 \times 13000 \times .732 \times .366 = 133728$.

Whence $x = \sqrt{\frac{133728}{5}}$ inches, or 47 feet. In this cafe, the angle of deflection is not introduced.

When the deflection is confidered, as it fhould be in this cafe, we find it to be from the data of example 1, and the theorem for the deflection, as $30^2 : 5 :: \frac{1}{4}x^2 : \frac{5x^2}{3600}$.

Whence the cofine $= \sqrt{\left(1 - \frac{25x^2}{1800^2}\right)}$; and the abov equation becomes

$$\frac{5x}{96} = \frac{2 \times 13000 \times .732 \times .366}{\frac{1}{2}x \sqrt{\left(1 - \frac{25x^2}{1800^2}\right)}};$$

which produces a cubic equation, whence the value of x may be determined.

It remains now to add a few particulars relative to the tranfverfe ftrength of ftones and metals, but our information on this head is limited; very few experiments having yet been attempted, except thofe of Mr. Banks on bars of caft-iron, and a few made by Dr. Robifon on fmall pieces of marble.

Mr. Banks has, at various times, made many experiments on the real and comparative ftrength of oak, fir, and iron. He found that the worft or weakeft piece of dry heart of oak, 1 inch fquare and 1 foot long, bore 660 lbs., though it was much bent, and 2 lbs. more broke it. The ftrongeft piece he tried of the fame dimenfions broke with 974 lbs.; the worft piece of deal bore 460 lbs.; but broke with a little more.

With refpect to caft-iron, he concludes that a bar of the weakeft kind, an inch fquare and a foot long, would break with 2190 lbs.

The following are fome of the experiments he mentions. See Banks on Power of Machines.

Experiment 1.—Two bars of caft-iron, 1 inch fquare and 3 feet long, were placed upon a horizontal bar, fo as to meet in a cap at the top, from which was fufpended a fcale: thefe bars made each an angle of 45° with the bafe-plate, and, of confequence, formed an angle of 90° at the top: from this cap was fufpended a weight of 7 tons, which was left for 16 hours, when the bars were a little bent, but very little.

Experiment 2.—Two bars, of the fame length and thicknefs, were placed in a fimilar manner, making an angle of 22½° with the bafe-plate: thefe bore four tons upon the fcale; a little more weight broke one of them, which was obferved to be a little crooked when firft put up. In this cafe, the preffures would be as the fines of the angles of elevation, *viz.* as 3826 to 7071; and as 3826 : 7071 :: 4 tons : 7.6 tons: that is, if the fecond bars broke with 4 tons, the firft ought to have taken 7.6 tons to break them; and it is likely that would, if tried, have been the cafe.

Experiment 3.—Another bar was placed horizontally upon two fupporters, exactly three feet diftant, which bore 6 cwt. 3 qrs., or 675 lbs., but broke when a little more was added.

Experiment 4.—The fame experiment repeated, with the fame refult.

Experiment 5.—The bearings were 2 feet 6 inches apart; the bar broke with 9 cwt. Three more experiments were tried at 3 feet; the average refult was 6 cwt. 2 qrs. 7½ lbs.

Experiments tried at Colebroke-Dale, on curved Bars of Caft-Iron.

1. Rib 29 feet 3 inches fpan, a fegment of a circle 3 feet high in the centre; it fupported 99 cwt. 1 qr. 14 lbs.; it funk in the middle 3⅞ inches, and rofe again three-fourths when the weights were removed: the fame rib was afterwards tried without abutments, and broke with 55 cwt. 0 qr. 14 lbs.

2. Rib 29 feet 3 inches fpan, a fegment of a circle 3 feet high in the centre; it fupported 100 cwt. 1 qr. 14 lbs., and funk $1\frac{3}{16}$ in the middle. The fame rib was afterwards tried without abutments, and broke with 64 cwt. 1 qr. 14 lbs. The thicknefs of thefe ribs is not fpecified; but the experiments prove that each rib exerted little more than half the ftrength when the abutments were removed.

Mr. Banks made fome experiments on the ftrength of caft-iron, at Meffrs. Aydon and Elwell's foundery, Wakefield. The iron came from their furnace at Shelf, near Bradford, and was caft from the air-furnace; the bars 1 inch fquare, and the props exactly 3 feet diftant; one yard in length weighed exactly 9 lbs., or one was about half an ounce lefs, the other a very little more; they all bent about an inch before they broke.

1. The firft bar broke with -	963 lbs.
2. The fecond bar with -	958
3. The third bar with -	994
4. A bar made from the cupola	864
5. A bar equally thick in the middle, but the ends formed into a parabolic form, and weighing 6 lbs. 3 oz. - - -	874

The fame gentleman made many other experiments, and concludes, from the whole, that caft-iron is from 3⅓ to 4½ times ftronger than oak of the fame dimenfions; and from 5 to 6½ times ftronger than deal.

We fhall only obferve here, that Mr. Banks's pieces of oak exceed very confiderably the fpecimens that we have had an opportunity of trying, while his fir falls fomewhat fhort of ours.

It was our intention, in conclufion, to have added a few examples illuftrative of the feveral rules and principles laid down in the preceding pages; and alfo inveftigations relative to the form of beams poffeffing equal ftrength throughout, or beams of equal refiftance; but as this article has already exceeded the ufual limits, we can merely ftate the refults, and muft leave the inveftigation to the reader; or we may refer him to Gregory's Treatife of Mechanics, where all thefe fubjects are inveftigated at length.

As the ftrefs upon any beam fubmitted to a tranfverfe ftrain is directly as the length, and the ftrength directly as the breadth into the fquare of the depth; it follows, if the fections are fo proportioned to the lengths, that the breadth

into the ſquare of the depth is always as the length or diſtance from the point where the weight acts; that every part of the beam will be equally ſtrong, in which caſe it is ſaid to be a beam of equal reſiſtance: hence, when a beam is fixed with one end in a wall,

1. If the breadth is the ſame throughout, the lengths muſt be as the ſquare of the depths; and conſequently the vertical ſides of the beam will be parabolas.

2. If the depth is the ſame throughout, the breadths muſt be as the lengths, and the upper and lower ſides of the beam will be triangles.

3. If the ſeveral ſections be circles, the cubes of their diameters (which is equivalent to the breadth into the ſquare of the depth) muſt be as the lengths; and the curve will be the cubic parabola.

4. The ſtrongeſt beam that can be cut out of any cylindrical beam or tree, is that in which the breadth into the ſquare of the depth is a maximum; which will be the caſe when the ſquares of breadth and depth, and the ſquare of the cylinder's diameter, are to each other as the numbers 1, 2, and 3.

As to our fourth head, relative to the wrenching or twiſting of a body, very little that is ſatisfactory can be advanced; according to Mr. Banks, a caſt-iron bar an inch ſquare, and fixed at one end, will break by the twiſt when 631 pounds are ſuſpended by a wheel of two feet diameter, and made to act upon it; though ſome have required more than 1000 lbs. in ſimilar ſituations, to break them by the twiſt. The ſtrength to reſiſt the twiſting ſtrain is as the cube of like lateral dimenſions.

Sugar

SUGAR, SACCHARUM, a very ſweet, agreeable ſaline juice, expreſſed from a kind of canes, or reeds, growing in great plenty in the Eaſt and Weſt Indies. (See SUGAR-*Cane.*) Pure ſugar is perfectly tranſparent and colourleſs, when cryſtallized; but when granular, of a pure gloſs of white, ſoluble in water and alcohol, without ſmell, and with a ſimply ſweet taſte, having no other flavour.

It is a queſtion not yet decided among botaniſts, &c. whether the ancients were acquainted with this cane, and whether they knew how to expreſs the juice from the ſame? What we can gather from the arguments advanced on either ſide is, that if they knew the cane, and juice, they did not know the art of condenſing, hardening, and whitening it; and of conſequence, they knew nothing of our ſugar.

Some ancient authors, indeed, ſeem to mention ſugar under the name of *Indian ſalt;* but they add, that it oozed out of the cane itſelf, and there hardened like a gum; and was even friable between the teeth, like our common ſalt; whereas ſugar is expreſſed by a machine on purpoſe, and coagulated by the fire.

Theirs, Salmaſius (Plinianæ Exercit. tom. i. p. 716. G.) tells us, was cooling and looſening; whereas ours, the ſame author aſſerts, is hot, and excites thirſt. Hence ſome have imagined, that the ancient and modern ſugar plants were different: but Matthiolus on Dioſcorides, c. 75. makes no doubt they were the ſame; and others are even of opinion, that ours has a laxative virtue, as well as that of the ancients, and that it purges pituita.

The generality of authors, however, agree, that the ancient ſugar was much better than the modern; as conſiſting of only the fineſt and matureſt parts, which made themſelves a paſſage, and were condenſed in the air. The interpreters of Avicenna and Serapion call ſugar, *ſpodium;* the Perſians, *tabaxir;* and the Indians, *mambu.* Salmaſius (Com. de Sacchar. apud Plin. Exercit. vol. ii. p. 257. A.D. 1689) aſſures us that the Arabs have uſed the art of making ſugar, ſuch as we now have it, above nine hundred years.

Others produce the following verſes of P. Terentius Varro Atacinus, to prove that it was known before Jeſus Chriſt:

> "Indica non magna nimis arbore creſcit arundo:
> Illius e lentis premitur radicibus humor,
> Dulcia cui nequeant ſucco contendere mella."

Dr. William Douglas, in his Summary, &c. of the firſt planting of our American ſettlements, printed at Boſton in 1751, and reprinted at London in 1755, affirms, that ſugar was not known among the ancient Greeks and Romans, who uſed only honey for ſweetening. Paulus Ægineta, he ſays, a noted compiler of medical hiſtory, and one of the laſt Greek writers on that ſubject, about anno 1625, is the firſt who expreſsly mentions ſugar: it was at firſt called *mel arundinaceum,* i. e. *reed or cane honey.* He adds that it came originally from China, by way of the Eaſt Indies and Arabia, into Europe, and was formerly uſed only in ſyrups, conſerves, and ſuch Arabian medicinal compoſitions.

Lucan, enumerating the eaſtern auxiliaries of Pompey, deſcribes a people who uſed the cane-juice as a common drink.

> "Qui bibunt tenerâ dulces ab arundine ſuccos."

Another queſtion among the naturaliſts is, whether the ſugar-canes be originally of the Weſt Indies, or whether they have been tranſlated rather from the Eaſt?

The learned of theſe laſt ages have been much divided on the point; but F. Labat, a Dominican miſſionary, in a diſſertation publiſhed in 1722, aſſerts, that the ſugar-cane is as natural to America as India; and that the Spaniards and Portugueſe firſt learned from the Orientals the art of expreſſing its juice, boiling it, and reducing it into ſugar.

Thoſe who adopt this opinion aſſert, that the ſugar-cane

was found growing ſpontaneouſly in many parts of the new hemiſphere, when firſt explored by the Spaniſh invaders. In ſupport of this opinion, Labat quotes, among other authorities, that of Thomas Gage, an Engliſhman, who went to New Spain in 1625, and who enumerates ſugar-canes among the fruits and proviſions with which the Charaibes of Guadaloupe ſupplied the crew of his ſhip. Labat further adds, that, beſides the evidence of Francis Ximenes, who, in a treatiſe on American plants, printed at Mexico, aſſerts that the ſugar-cane grows without cultivation, and to an extraordinary ſize, on the banks of the river Plata, we are aſſured by Jean de Lery, a Proteſtant miniſter, who was chaplain, in 1556, to the Dutch garriſon in the fort of Coligny, on the river Janeiro, that he himſelf found ſugar-canes in great abundance in many places on the banks of that river, and in ſituations never viſited by the Portugueſe. Father Hennepen, and other voyagers, bear teſtimony, in like manner, to the growth of the cane near the mouth of the Miſſiſippi; and Jean de Laet to its ſpontaneous production in the iſland of St. Vincent. Hence it is concluded, that it is not for the plant itſelf, but for the ſecret of making ſugar from it, that the Weſt Indians are indebted to the Spaniards and Portugueſe; and theſe to the nations of the Eaſt. Thus Labat reaſons, and Laſitau is of opinion that his reaſoning is incontrovertible; and it is alſo greatly confirmed by recent diſcoveries; the ſugar-cane having been found in many of the iſlands of the Pacific ocean, by our late illuſtrious navigator captain Cook. In theſe accounts, ſays Mr. B. Edwards, there is no contradiction. The ſugar-cane might have grown ſpontaneouſly in many parts of the new world; and Columbus, unapprized of the circumſtance, might likewiſe have carried ſome of the plants to Hiſpaniola; and this moſt probably was the fact.

However this be, the induſtry with which the Spaniſh ſettlers applied to its cultivation, affords a wonderful contraſt to the manners of the preſent inhabitants; ſince it appears, by the teſtimony of Oviedo, that no leſs than 30 ingenios, or ſugar-mills, were eſtabliſhed on that iſland ſo early as the year 1535.

Other writers, however, have maintained, that it was not known in America till the Europeans tranſplanted it thither. Its origin appears to have been from the inland continent of Aſia, very probably as far eaſt as China, where it ſtill greatly abounds. From that continent it was firſt tranſplanted to Cyprus, and thence (according to various authors) into Sicily, where conſiderable quantities of it were produced about the year 1148, and whither, as ſome have aſſerted, it was brought from India by the Saracens. Laſitau conjectures, that the plant itſelf was unknown in Chriſtendom, until the time of the Cruſades. Its cultivation, and the method of expreſſing and purifying the juice, as practiſed by the inhabitants of Acra and Tripoli, are deſcribed by Albertus Aquenſis, a monkiſh writer, who obſerves, that the Chriſtian ſoldiers in the Holy Land frequently derived refreſhment and ſupport, in a ſcarcity of proviſions, by ſucking the canes. It flouriſhed alſo in the Morea, and in the iſlands of Rhodes and Malta, and from thence was tranſported into Sicily, but the time is not preciſely aſcertained. Laſitau recites a donation of William, the ſecond king of Sicily, to the monaſtery of St. Bennet, of a mill for grinding ſugar-canes, with all its rights, members, and appurtenances. This happened in 1166. From Sicily it was tranſplanted by the Portugueſe to Madeira about the year 1420, and from Sicily, or the ſouthern coaſts of Africa, or, as Herrera, the American hiſtorian, obſerves, from Granada, which derived it from Valencia, whither it might have been tranſplanted by the Arabian Moors, it was brought to the Canaries; from the Canary iſles to Braſil; where, indeed, ſome ſuppoſe ſugar was originally and ſpontaneouſly produced. Others are of opinion, that the Portugueſe, before they diſcovered, or at leaſt planted in Braſil, being in poſſeſſion of the coaſt of Angola in Africa, firſt tranſplanted the ſugar-cane from Angola to Braſil. About the year 1506, ſugar-canes were brought from Braſil and the Canaries, and planted in the iſland of Hiſpaniola, where many ſugar-mills were gradually erected. It appears, however, by the teſtimony of Peter Martyr, in the third book of his firſt Decad, written during Columbus's ſecond expedition, which began in 1493 and ended in 1495, that the ſugar-cane was at that period ſufficiently known in Hiſpaniola. The fact ſeems to have been, that Columbus himſelf carried it thither, among other articles and productions which he conveyed from Old Spain, and the Canary iſlands, where it grew, in his ſecond voyage. In 1641, ſugar-canes were tranſplanted from Braſil to Barbadoes, and thence to our other Weſt India iſles: as from Braſil they were alſo carried to the Spaniſh Weſt India iſles, and alſo the Spaniſh dominions in Mexico, Peru, and Chili; and laſtly, to the French, Dutch, and Daniſh colonies.

The boiling and baking of ſugars, ſays Dr. Heylin in his Coſmography, the firſt edition of which was printed in 1624, as it is now uſed, is not above two hundred years old; and the refining of it more new than that, firſt found out by a Venetian in the days of our forefathers, who got one hundred thouſand crowns by the invention. Before which art of boiling and refining it, our anceſtors made uſe of it rough as it came from the canes, but they moſt commonly uſed honey inſtead of it. The firſt account we have of ſugar-refiners in England is in the year 1659. Anderſon's Hiſt. of Com. vol. i. p. 82. 246. 331. 334. vol. ii. p. 72—105.

Sugar-*Cane*, in *Botany*. See Saccharum.

The root of this plant is jointed like thoſe of the other ſorts of canes and reeds, from which ariſe four, five, or more ſhoots, according to the age or ſtrength of the root: theſe grow from eight or ten to twenty feet high, according to the richneſs of the ground; but thoſe of middling growth are the beſt.

The canes are alſo jointed, and the length as well as the ſize of the joints depend upon the weather and the ſoil; at each joint are placed leaves, the lower part of which embraces the ſtalk or cane to the next joint above their inſertion, before they expand. The firſt joint, which comes out either at the third, fourth, or fifth month, according to the ſeaſon and ſoil, always keeps in its firſt place near the earth; out of this comes the ſecond, and out of the ſecond a third, &c. each week producing its joint, or very nearly, and a correſponding leaf likewiſe drying and falling off nearly every week.

A cane of thirty-two joints, which is fit to be cut, has from five to twenty-eight of them which have loſt their leaves; the next five or ſix ſtill have them, in a withered ſtate, and ready to fall off; and the remaining joints, ſurrounded with green leaves, form the head, which is cut off after the laſt leaf is withered. In a cane, whoſe length is from ſeven to nine feet, and which grows in a new, or a very moiſt and favourable ſoil, the number of uſeful joints is between forty and fifty, the firſt above the ground generally appearing at the end of three months, or, with frequent ſhowers, a fortnight ſooner; and many canes in ſuch a ſoil are found rotten, or almoſt dried up, at the end of thirteen months: in a good ſoil, favourably expoſed, well drained, and worked for a number of years, canes not ſhorter than four feet and a half have thirty-eight or forty joints, the firſt

joint appearing about the fourth or middle of the third month, and many canes that have been cut in ſuch a ſoil at the end of fourteen or fifteen months being found rotted or dried: in a dry, but good ſoil, not manured, but well worked, and ſeconded by the ſeaſon, the canes have been from three to four feet long, and have had from thirty to thirty-four joints; the firſt joint coming out at the end of four or four months and a half; and canes of this kind have been found ſtanding at the end of fifteen months, but very dry, and ſometimes a little changed: in a ſoil which is ſtill drier, and more parched, canes which have been about two feet high have had from twenty-four to twenty-eight joints, the firſt of which appears at the end of the fifth month, and many of theſe canes have been dried at the end of fifteen months. From theſe and ſimilar obſervations on the growth of canes in various kinds of ſoil, it has been inferred, that if there be any in which they can exiſt till the fifteenth or ſixteenth month, they never grow to any kind of purpoſe in any after the thirteenth, or even after the twelfth. A deep ſoil and light land are moſt ſuitable to the ſugar-cane; and the rainy ſeaſon is the proper time for planting it: the ſooner they are planted after the rains begin to fall, the more time they have to get ſtrength before the dry weather ſets in.

If the ground is proper for the ſugar-canes, and they are planted at a good diſtance from each other, and the land is carefully managed by changing the crops to other ſpecies, or allowing a fallow to reſt and recover itſelf, the ſame plantation, ſays Mr. Miller, may be continued above twenty years without replanting, and produce good crops the whole time: whereas in the common method, they are generally replanted in ſix or ſeven years, and in ſome of the poor land they are continued but two or three years. The canes are propagated by cuttings or joints of proper lengths, from fifteen to twenty inches, in proportion to the nearneſs of the joints; which are generally taken from the tops of the canes, juſt below the leaves: but Mr. Miller ſays, that if they were choſen from the lower part, where they are leſs ſucculent and better ripened, they would not produce canes ſo luxuriant, but their juice would be leſs crude, and contain a greater quantity of ſalts, which would be obtained by leſs boiling than that of thoſe commonly planted. However, Mr. Cazaud, a late writer, and a planter of ſugar-canes, obſerves, that the upper part, commonly called the head, is the beſt part that can be uſed for propagating them; and he recommends to put the plant in the ground as ſoon as it is cut. The diſtance which the canes are uſually allowed in planting is from three to four feet, row from row; and the hills are about two feet aſunder in the rows, in each of which hills they plant from four to ſeven or eight cuttings: inſtead of which number, productive often of blights, Mr. Miller is of opinion, that if one good cutting were planted in each hill, or two at moſt; and if both ſucceeded, the weakeſt were drawn out ſoon after they had taken, blights would be prevented, and the quantity of ſugar would be full as great, and require little more than a fourth part of the fuel to boil it. In the proper ſeaſon for planting, the ground ſhould be marked out by a line, that the rows of canes may be ſtraight and at equal diſtances; and the whole ſhould be divided into pieces of ſixty or ſeventy feet broad, leaving intervals between each of about twenty feet, for the convenience of paſſage, and for the admiſſion of the ſun and air between the canes.

The common method of planting the canes now practiſed, is to make a trench with the hoe, which is performed by the hand; into this a negro drops the number of cuttings intended to be planted, which are planted by other negroes, and the earth drawn about the hills with the hoe, all which is performed by the hand: but if the right uſe of the plough was introduced, the work would be both better and cheaper performed. If, therefore, inſtead of a trench drawn by the hoe, a deep furrow is made with a plough, and the cuttings properly planted therein, the ground being deeper ſtirred, will be more favourable to the growth of the canes.

If the ground is afterward to be kept clear by the horſe-hoe, the rows of canes ſhould be five feet aſunder, and the hills be two feet and a half diſtant; and but one cane left in each hill. After they have made ſome ſhoots, the ſooner the horſe-hoe is uſed, the more they will thrive, by keeping the weeds under, and well ſtirring the land.

When the canes are from ſeven to ten feet high, and of proportionable ſize, the ſkin ſmooth, dry, and brittle; if they are heavy, their pith grey or inclinable to brown, the juice ſweet and glutinous; they are eſteemed in perfection.

Mr. Cazaud obſerves, that the withering and fall of a leaf is the only and a ſufficient criterion of the maturity of the joint to which it adhered; and that the eight laſt joints of two canes, which are cut the ſame day, have exactly the ſame age and the ſame degree of ripeneſs, notwithſtanding one of the canes may be fifteen, and the other only ten months old: to which purpoſe he adds, that each joint of the cane of a ſuppoſed growth of ten months, contained the ſame quantity of ſugar as that of a cane of the ſuppoſed growth of fifteen.

The time for cutting them is uſually after twelve or fifteen months growth, but this varies according to the ſoil and the ſeaſon. Thoſe which are cut toward the end of the dry ſeaſon, before the rains begin to fall, produce better ſugar than thoſe cut in the rainy ſeaſons, when they are more replete with watery juice, and require a greater expence of fuel to boil it.

In thoſe plantations where the number of negroes is ſmall, ſugar is made in almoſt all ſeaſons indifferently, and conſequently the canes are planted when the planter is beſt prepared for his work, rather than at the moſt advantageous time. The ſyſtem of cultivation among planters, who are better ſupplied in reſpect of labourers, conſiſts in planting a fourth or a fifth of their land in October, November, and December; in digging very deep trenches, for the greater nouriſhment of the root; in planting at great diſtances, for the benefit of a freer circulation of the air; and in cutting the canes in the four fineſt months, *viz.* February, March, April, and May, becauſe the ſugar is then the fineſt, the canes are cut with the leaſt trouble, and ſupply (as is ſuppoſed) greater quantities of it. Thoſe who adopt this method, cut about three-fourths of their plantations, the remaining being made up of young canes, to be cut the following year, and for new plants.

Mr. Cazaud, who has made many judicious obſervations and experiments on the cultivation of the ſugar-cane, has adopted a new method. He employs the whole of the firſt ſix months of the year in the buſineſs of the crop, and in May and June plants the canes which have been cut in January. This of courſe induces a neceſſity of cutting the rattoons (or the canes proceeding from the old ſtumps) at the end of the eleventh inſtead of the end of the twelfth month, and the planted canes, which ſhould ſtand fifteen months, at the end of the year; ſo that the whole plantation is cut every year; and he only plants a ſixth part of his land every year. He has largely illuſtrated the reaſons and advantages of this method; the fundamental principle of which is the neceſſity of planting the canes in the only

seafon fitted to accelerate and preferve them: as in the Windward iflands, the weather is commonly dry from the 15th of February to the 15th of May, and the rains are moderate till Auguft, and copious the two or three following months, and afterwards decreafe till February: and, therefore, the progreffion of the rain keeps pace, as it were, with that of the canes, when they are planted in May. With regard to the maturity of the cane, as far as it is of confequence to the fugar, this, he fays, does not depend on the age, but on the feafon. In February, March, and April, all the canes, whatever be their age, are as ripe as the nature of the foil ever allows them to be; and accordingly he never fails to make the greateft part of his fugar at this feafon. He obferves, that the drynefs of the weather, (and not the age of the canes,) which increafes from January to April, is the caufe, that in January four hundred gallons of juice commonly yield forty-eight gallons of fugar and melaffes one with another; in February, from fifty-fix to fixty-four; in March, from fixty-four to feventy-two; in April, fometimes eighty; after which period the fugar ferments, and even burns when the refiner is not very expert at his bufinefs. The greateft relative maturity of his canes he infers to be, when the juice of them was made up of four parts water, and one part of fugar and melaffes: and in canes perfectly ripe, the quantity of fugar, he fays, is equal to that of the melaffes. After a trial of this plan for five years, he is convinced that there is a difference of above one-fixth in its favour. Miller's Gard. Dict. Phil. Tranf. vol. lxix. part 1. art. xix. p. 207, &c.

The beft foil, according to Mr. Edwards, which he has feen or heard of, for the production of fugar of the fineft quality, and in the largeft proportion, is the afhy loam of St. Chriftopher's. Next to that is the foil, which in Jamaica is called the brick-mould, containing a due mixture of clay and fand. Plant-canes in this foil (which are thofe of the firft growth) have been known, in very fine feafons, to yield two tons and a half of fugar *per* acre. After this may be reckoned the black mould of feveral varieties. The beft is the deep black earth of Barbadoes, Antigua, and fome other of the Windward iflands; but there is a fpecies of this mould in Jamaica, that is little if at all inferior to it, which abounds with lime-ftone and flint, on a fubftratum of foapy marle. We fhall not enumerate the varieties of foil proper for this kind of culture; but content ourfelves with mentioning a peculiar fort of land on the north fide of Jamaica, chiefly in the parifh of Trelawney, as few foils produce finer fugars, or fuch as anfwer fo well in the pan, or which yield a greater return of refined fugar. This land is of a red colour, varying by different fhades; but every where remarkable, when firft turned up, for a gloffy or fhining furface, and, if wetted, for ftaining the fingers like paint. This foil feems to confift of a native earth, or pure loam, with a mixture of clay and fand. It is eafily wrought, and at the fame time fo tenacious, that a pond dug in this foil in a proper fituation, with no other bottom than its own natural texture, holds water like the ftiffeft clay. The fyftem of hufbandry in fugar plantations, which abound with this, chiefly depends on what are called rattoon-canes.

In moft parts of the Weft Indies, it is ufual to hole and plant a certain proportion of the cane-land (commonly one-third), in annual fucceffion. The common yielding of this land, on an average, is feven hogfheads of 16 cwt. to ten acres, which are cut annually. In the cultivation of other lands, efpecially in Jamaica, the plough has been introduced of late years, and in fome few cafes to great advantage; but the ufe of the plough is not adapted to every foil or fituation. The only advantageous fyftem of ploughing in the Weft Indies is to confine it to the fimple operation of *holing*, which is much more eafily and expeditioufly performed by the plough than by the hoe, and which affords, in the cafe of ftiff and dry foils, great relief to the negroes. The method of *holing* has been already defcribed. The proper feafon, generally fpeaking, for planting, is in the interval between Auguft and the beginning of November. By having the advantage of the autumnal feafon, the young canes become fufficiently luxuriant to fhade the ground before the dry weather fets in: thus the roots are kept cool, and the earth moift. By thefe means, they are ripe for the mill in the beginning of the fecond year, fo as to enable the overfeer or manager to finifh his crop by the latter end of May. It has been juftly remarked, that there is not a greater error in the fyftem of planting, than to make fugar, or plant canes, in improper feafons of the year; for by mifmanagement of this kind, every fucceeding crop is put out of regular order. However, neither prudence in the management, nor favourable foils, nor feafonable weather, will exempt the planter at all times from misfortune in the culture of his fugar-canes. They are fubject to a difeafe called the "blaft," which confifts of many myriads of little infects of the aphis genus, faid to be invifible to the unaffifted eye, whofe proper food is the juice of the cane; in purfuit of which they wound the tender blades, and deftroy the veffels. The circulation is thus impeded, and the growth of the plant is checked, until it withers or dies in proportion to the degree of the ravage. In fome of the Windward iflands, the cane in dry weather is liable to be deftroyed by a fpecies of grub, called the "borer." In Tobago they have another deftructive infect, called the "jumper-fly." It is faid that the "blaft" never attacks thofe plantations, where colonies have been introduced of the little animal, called the carnivorous ant; the "formica omnivora" of Linnæus, and the "Raffles" ant of Jamaica.

The manure generally ufed in fugar-planting is a compoft formed of the coal and vegetable afhes, drawn from the fires of the boiling and ftill-houfes; feculencies difcharged from the ftill-houfe, mixed with rubbifh of buildings, white lime, &c.; refufe, or field-trafh, *i. e.* the decayed leaves and ftems of the canes, fo called in contradiftinction to cane-trafh ufed for fuel; dung, obtained from the horfe and mule ftables, and from cattle-pens; and good mould, collected from gullies, or other wafte places, and thrown into the cattle-pens.

When the rattoons or canes are ripe, as they ordinarily are in twelve or fifteen months, or, as Mr. Cazaud apprehends, in eleven or twelve months, they are cut, and carried in bundles to the mills. The mills confift of three wooden rollers, covered with fteel or iron plates; and have their motion either from the water, the wind, cattle, or even the hands of flaves. Thefe rollers or cylinders are from 30 to 40 inches in length, and from 20 to 25 inches in diameter; and the middle one, to which the moving power is applied, turns the other two by means of cogs. Between thefe rollers the canes, being previoufly cut, are twice compreffed; for having paffed the firft and fecond rollers, they are turned round the middle one by a circular piece of frame-work, or fcrew, called in Jamaica the "dumb-returner," and forced back through the fecond and third; an operation which fqueezes them completely dry, and fometimes even reduces them to powder. (For a farther account of fugar-mills, fee the fequel of this article.) The juice from the mill ordinarily contains eight parts of pure water, one part of fugar, and one part made of grofs oil and mucilaginous gum, with a portion of effential oil. Some juice, however, has been fo rich

as to make a hogſhead (16 cwt.) of ſugar from 1300 gallons; and ſome ſo watery as to require more than double that quantity. A pound of ſugar from a gallon of raw liquor is reckoned, in Jamaica, very good yielding.

SUGAR, *Preparation of.* The juice or liquor runs from the receiver to the boiling-houſe, along a wooden gutter lined with lead. In the boiling-houſe it is received (according to the modern improved ſyſtem, which almoſt univerſally prevails in Jamaica) into one of the copper pans or cauldrons, called clarifiers. Of theſe, there are commonly three; and their dimenſions are generally determined by the power of ſupplying them with liquor. There are water-mills that will grind, with great eaſe, canes ſufficient for thirty hogſheads of ſugar in a week. On plantations thus happily provided, the means of quick boiling are indiſpenſably requiſite, or the cane-liquor will unavoidably become tainted before it can be expoſed to the fire. The pureſt cane-juice will not remain twenty minutes in the receiver without fermenting. As cane-juice is ſo very liable to fermentation, it is neceſſary alſo that the canes ſhould be ground as ſoon as poſſible after they are cut, and great care taken to keep and throw aſide thoſe which are tainted, which may afterwards be ground for the ſtill-houſe. Clarifiers, therefore, are ſometimes ſeen of one thouſand gallons each. On eſtates that make on a medium, during crop-time, from fifteen to twenty hogſheads of ſugar a week, three clarifiers of three or four hundred gallons each are ſufficient. With pans of this ſize, the liquor, when clarified, may be drawn off at once; and there is leiſure to cleanſe the veſſels every time they are uſed. Each clarifier is provided either with a ſiphon or cock for drawing off the liquor. It has a flat bottom, and is hung to a ſeparate fire, each chimney having an iron ſlider, which being ſhut, the fire goes out for want of air. Theſe circumſtances are indiſpenſable, and the advantages of them will preſently be ſhewn. The clarifiers are commonly placed in the middle or at one end of the boiling-houſe. If at one end, the boiler called the "teache" is placed at the other, and ſeveral boilers (generally three) are ranged between them. The teache is ordinarily from 70 to 100 gallons, and the boilers between the clarifiers and teache diminiſh in ſize from the firſt to the laſt. Where the clarifiers are in the middle, there is uſually a ſet of three boilers on each ſide, which conſtitute in effect a double boiling-houſe. On very large eſtates, this arrangement is found uſeful and neceſſary. The objection to ſo great a number is the expence of fuel; to obviate which, in ſome degree, the three boilers on each ſide of the clarifiers are commonly hung to one fire.

The ſtream then from the receiver having filled the clarifier with freſh liquor, and the fire being lighted, the "temper," which is commonly Briſtol white-lime in powder, is ſtirred into it. One great intention of this is to neutralize the ſuperabundant acid, to get properly rid of which, is the great difficulty in ſugar-making. This is generally effected by the alkali or lime; part of which, at the ſame time, becomes the baſis of the ſugar. The quantity neceſſary for this purpoſe muſt, of courſe, vary with the quality both of the lime and of the cane-liquor. Some planters allow a pint of Briſtol lime to every hundred gallons of liquor; but this proportion is, Mr. Edwards believes, generally found too large. The lime is perceptible in the ſugar, both to the ſmell and taſte, and precipitates in the copper pans a black inſoluble calx, which ſcorches the bottom of the veſſels, and is not detached without difficulty. Mr. Edwards is of opinion, therefore, that little more than half the quantity mentioned above is a better medium proportion; and, in order that leſs of it may be precipitated to the bottom, an inconveniency attending the uſe of dry lime, Mr. Bouſie's method of diſſolving it in boiling water, previous to mixing it with the cane-juice, appears to him to be highly judicious. In ſome parts of Jamaica, where the cane-liquor was exceedingly rich, Mr Bouſie made very good ſugar without a particle of temper. Too much temper is perceptible in the ſugar, both to the ſmell and taſte: it might be added, *and alſo to the ſight.* It tinges the liquor firſt yellow, and, if in exceſs, turns it to a dark red. Too much temper likewiſe prevents the melaſſes from ſeparating from the ſugar, when it is potted or put into the hogſhead.

As the fire increaſes in force, and the liquor grows hot, a ſcum is thrown up, which is formed of the mucilage or gummy matter of the cane, with ſome of the oil, and ſuch impurities as the mucilage is capable of entangling. The heat is now ſuffered gradually to increaſe, until it riſes to within a few degrees of the heat of boiling water. The liquor muſt by no means be ſuffered to boil: it is known to be ſufficiently heated, when the ſcum begins to riſe into bliſters, which break into white froth, and appear in general in about forty minutes. The damper is then applied, and the fire extinguiſhed; after which, the liquor is ſuffered to remain a full hour, if circumſtances will permit, undiſturbed. During this interval, great part of the feculencies and impurities will attract each other, and riſe in the ſcum. The liquor is now carefully drawn off, either by a ſiphon, which draws up a pure defecated ſtream through the ſcum, or by means of a cock at the bottom. In either caſe, the ſcum ſinks down unbroken as the liquor flows, its tenacity preventing any admixture. The liquor is received into a gutter or channel, which conveys it to the evaporating boiler, commonly called the "grand copper;" and, if originally produced from good and untainted canes, will now appear almoſt, if not perfectly, tranſparent. The merit of introducing into Jamaica the clarifiers at preſent in uſe with ſiphons and dampers, was claimed by Mr. Samuel Sainthill; and an excluſive patent, to ſecure his claim, was granted to him in 1778, by an act of the aſſembly.

The advantage of clarifying the liquor in this manner, inſtead of forcing an immediate ebullition, as practiſed formerly, is viſible to the moſt inattentive obſerver. The labour which it ſaves in ſcumming is wonderful. Neither can ſcumming properly cleanſe the ſubject; for when the liquor boils violently, the whole body of it circulates with ſuch rapidity, as to carry down again the very impurities that had come up to the ſurface, and which with a leſs violent heat would have ſtaid there.

In the grand or evaporating copper, which ſhould be large enough to receive the net contents of one of the clarifiers, the liquor is ſuffered to boil; and as the ſcum riſes, it is continually taken off by large ſcummers, until the liquor grows finer and ſomewhat thicker. This labour is continued until, from the ſcumming and evaporation, the ſubject is ſufficiently reduced in quantity to be contained in the next or ſecond copper, into which it is then laded. The liquor is now nearly of the colour of Madeira wine. In the ſecond copper the boiling and ſcumming are continued; and if the ſubject is not ſo clean as is expected, lime-water is thrown into it. This addition is intended not merely to give more temper, but alſo to dilute the liquor, which ſometimes thickens too faſt to permit the feculencies to run together, and riſe in the ſcum. Liquor is ſaid to have a good appearance in the ſecond copper, when the froth in boiling ariſes in large bubbles, and is but little diſcoloured. When, from ſuch ſcumming and evaporation, the liquor is again ſufficiently reduced to be contained in the third copper, it

is laded into it, and so on to the last copper, which is called the "teache," probably from the practice of trying by the touch. This arrangement supposes four boilers or coppers, exclusive of the three clarifiers.

In the teache the subject is still farther evaporated, till it is judged sufficiently boiled to be removed from the fire. This operation is usually called "striking," *i. e.* lading the liquor, now exceedingly thick, into the cooler.

The cooler, of which there are commonly six, is a shallow wooden vessel, about eleven inches deep, seven feet in length, and from five to six feet wide. A cooler of this size holds a hogshead of sugar. Here the sugar grains; *i. e.* as it cools, it runs into a coarse irregular mass of imperfect semi-formed crystals, separating itself from the melasses. From the cooler it is carried to the curing-house, where the melasses drain from it. It may be proper in this place to observe, that, in order to obtain a large-grained sugar, it must be suffered to cool slowly and gradually. If the coolers are too shallow, the grain is injured in a surprising manner. Any person may be convinced of this, by pouring some of the hot syrup, when fit for striking, into a pewter plate: he will immediately find it will have a very small grain.

But, before we follow it into the curing-house, it may be proper to notice the rule for judging when the subject is sufficiently evaporated for "striking," or become fit for being laded from the teache to the cooler. Many of the negro boilers guess solely by the eye, (which by long habit they do with great accuracy,) judging by the appearance of the grain on the back of the ladle; but the practice most in use is to judge by what is called "the touch;" *i. e.* taking up with the thumb a small portion of the hot liquor from the ladle; and, as the heat diminishes, drawing with the fore-finger the liquid into a thread. This thread will suddenly break, and shrink from the thumb to the suspended finger, in different lengths, according as the liquor is more or less boiled. The proper boiling height for strong muscovado sugar is generally determined by a thread of a quarter of an inch long. It is evident, that certainty in this experiment can be attained only by long habit; and that no verbal precepts will furnish any degree of skill in a matter depending wholly on constant practice.

A method more certain and scientific was recommended some years ago, by John Proculus Baker, esq., barrister at law, in the island of Jamaica, in a treatise published by him in 1775, entitled "An Essay on the Art of making Muscovado Sugar." It is as follows: "Provide a small thin pane of clear crown glass, set in a frame, which I would call a 'tryer;' on this drop two or three drops of the subject, one on the other, and carry your tryer out of the boiling-house into the air. Observe your subject, and more particularly whether it grains freely, and whether a small edge of melasses separates at the bottom. I am well satisfied that a little experience will enable you to judge what appearance the whole skip will put on, when cold, by this specimen, which is also cold. This method is used by chemists, to try evaporated solutions of all other salts; it may seem, therefore, somewhat strange, it has not been long adopted in the boiling-house."

The present improved system of clarifying the cane-liquor, by means of vessels hung to separate fires, and provided with dampers to prevent ebullition, was first suggested, says Mr. Edwards, to Mr. Sainthill, (who three years afterwards claimed the merit of the invention,) by the treatise in question.

The curing-house is a large airy building, provided with a capacious melasses cistern, the sides of which are sloped and lined with terras, or boards. Over this cistern there is a frame of massy joist-work, without boarding. On the joists of this frame, empty hogsheads, without headings are ranged. In the bottoms of these hogsheads eight or ten holes are bored, through each of which the stalk of a plantain leaf is thrust, six or eight inches below the joists, and long enough to stand upright above the top of the hogshead. Into these hogsheads the mass from the cooler is put, which is called "potting;" and the melasses drain through the spongy stalk, and drop into the cistern, from whence it is occasionally taken for distillation. The sugar, in about three weeks, grows tolerably dry and fair. It is then said to be cured, and the process is finished. The curing-house should be close and warm, as warmth contributes to free the sugar from the melasses.

Sugar, thus obtained, is called "muscovado," and is the raw material from which the British sugar-bakers chiefly make their loaf, or refined lump. There is another sort, which was formerly much approved in Great Britain for domestic purposes, and was generally known by the name of Lisbon sugar. It is fair, but of a soft texture, and in the West Indies is called "clayed sugar." The process is conducted as follows: A quantity of sugar from the cooler is put into conical pots or pans, called by the French "formes," with the points downwards, having a hole about half an inch in diameter at the bottom, for the melasses to drain through, but which at first is closed with a plug. When the sugar in these pots is cool, and become a fixed body, which is discoverable by the middle of the top falling in, (generally about twelve hours from the first potting of the hot sugar,) the plug is taken out, and the pot placed over a large jar, intended to receive the syrup or melasses that drain from it. In this state it is left as long as the melasses continue to drop, which it will do from twelve to twenty-four hours, when a stratum of clay is spread on the sugar, and moistened with water, which oozing imperceptibly through the pores of the clay, unites intimately with, and dilutes the melasses; consequently more of it comes away than from sugar cured in the hogshead, and the sugar, of course, becomes so much the whiter and purer. The pots remain for twenty days in this situation, after which the sugar is taken out, dried in the sun for some hours, and then taken to a large store-room, where it is kept in a pretty strong heat for three weeks. The process, according to Sloane, was first discovered in Brasil, by accident. "A hen," says he, "having her feet dirty, going over a pot of sugar, it was found under her tread to be whiter than elsewhere." The reason assigned why this process is not universally adopted in the British sugar islands is this, that the water, which dilutes and carries away the melasses, dissolves and carries with it so much of the sugar, that the difference in quality does not pay for the difference in quantity. The French planters probably think otherwise, upwards of four hundred of the plantations of St. Domingo having the necessary apparatus for claying, and actually carrying on the system. The loss in weight by claying is about one-third: thus, a pot of 60 pounds is reduced to 40 pounds; but if the melasses which are drawn off in this practice be reboiled, they will give nearly 40 *per cent.* of sugar; so that the real loss is little more than one-sixth: but the distillery, in that case, will suffer for want of the melasses; and, on the whole, Mr. Edwards believes that the usage of the English planters in shipping muscovado sugar, and distilling the melasses, is more generally profitable than the system of claying.

The Cochinchinese prepare a very excellent moist sugar, remarkably cheap, by a very simple process, similar to that of claying. The grained sugar, after the gross syrup has drained from it, and it has become considerably solid, is

placed in layers about an inch thick, under layers of the ſame dimenſions of the herbaceous trunk of the plantain tree; the watery juices, exuding from which, act like claying, and leave the ſugar very white and porous, like a honey-comb. This is pure enough to diſſolve in water, without any ſediment.

F. Labat mentions ſeveral different kinds of ſugars, prepared in the Caribbees, *viz. Crude ſugar*, or *muſcovado; ſtrained*, or *brown ſugar; earthed*, or *white ſugar* in powder; *refined ſugar*, either in powder or loaves; *royal ſugar; candied ſugar; ſugar of fine ſyrup; ſugar of coarſe ſyrup; ſugar of the ſcum*.

SUGAR, *Crude*, or *Muſcovado*, is that firſt drawn from the juice of the cane; of which all the reſt are compoſed. The method of making it is that already deſcribed as for ſugar in the general.

SUGAR, *Strained*, or *Brown*, though ſomewhat whiter and harder, does not differ much from the crude ſugar; though it is held a medium between this laſt and the earthed ſugar; which is the white powder ſugar.

The preparation of this is the ſame as that of the muſcovado, with this difference, that, to whiten it, they ſtrain the liquor through blankets, as it comes out of the firſt copper. The invention of ſtrained ſugar is owing to the Engliſh, who are more careful than their neighbours in the preparation of it; for they not only ſtrain it, but, when boiled, put it into ſquare wooden forms, or moulds, of a pyramidal figure; and when it has purified itſelf well, they cut it in pieces, dry it in ſtoves, and barrel it up. See *Refining of* SUGAR, *infra*.

SUGAR, *Earthed*, is that which is whitened by means of earth laid on the top of the forms it is put in to purge itſelf. See *Refining of* SUGAR.

SUGAR *of the Scum*. This is all made of the ſcum of the two laſt coppers; thoſe of the former being reſerved for the making of rum.

The ſcum deſtined to make ſugar is kept in a veſſel for that purpoſe, and is boiled every morning in a copper ſet apart for that uſe. With the ſcum, is put into the copper a fourth part of water, to retard the boiling, and give time for its purging; when it begins to boil, the uſual ley is put in, and it is carefully ſcummed: when almoſt enough boiled, lime and alum-water are thrown in; and when it is ready to be taken out, they ſprinkle it with a little powdered alum.

SUGAR *of Syrup*, or *Treacle*. There are three kinds of ſyrups that run from ſugar. The firſt, from the barrels of raw ſugar, which is the coarſeſt of all; the ſecond, from the forms, or moulds, after they are perforated, and before they receive their earth; the third, that coming from the forms after they have had their earth; which laſt is the beſt.

The coarſe ſyrups ſhould only be uſed for rum, but ſugar being grown dear, endeavours have been uſed to make ſome of them, and that with tolerable ſucceſs. They are firſt clarified with lime-water: and, when boiled, are put up in barrels, with a ſugar-cane in the middle, to make them purify themſelves. After twenty days, a quantity of coarſe earth is thrown in, to make them caſt the remainder of their ſyrup, and fit them to be returned into a crude ſugar. The Dutch and German refiners firſt taught the iſlanders how to turn their treacle into ſugar.

The ſecond ſyrup is wrought ſomewhat differently: after the copper it is to be boiled in is half full, eight or ten quarts of lime-water are caſt in; it is then boiled with a briſk fire, and carefully ſcummed; ſome add a ley, and others none. F. Labat takes the former method to be the better, though it requires more trouble and attention. This ſugar may be earthed alone, or at leaſt with the heads of loaves, the dried tops, and ſuch other kinds of ſugars as may not be mixed with the true earthed ſugar, nor yet with the crude ſugar.

For the third ſyrup, after boiling and ſcumming it as the former, they put it inſtantly into coolers, the bottoms of which are covered half an inch thick with white ſugar, very dry and well pounded; and the whole is well ſtirred to incorporate the two together. This done, they ſtrew the ſurface over with the ſame pounded ſugar, to the thickneſs of one-fifth of an inch, this aſſiſting the ſugar in forming its grain. When ſettled, and the cruſt gathered at the top, a hole is made in the cruſt five or ſix inches in diameter.

By this aperture they fill the cooler with a new ſyrup, poured gently in, which inſenſibly raiſes up the former cruſt. When all the ſyrups are boiled, and the cooler is full, they break all the cruſts; and, after mixing them well, put them up in forms or moulds.

The reſt is performed in the ſame manner as for the earthed ſugar, from which it only differs in that it falls ſhort of its gloſs and brightneſs; being, in reality, ſometimes whiter and finer, though of a flatter and duller white. For the uſe and management of the ſyrup of ſugar, ſee *Refining of* SUGAR.

SUGAR, *Refined*. Crude ſugar, ſtrained ſugar, and the heads or tops of loaves that have not whitened well, are the baſis, or ground, of this ſugar. See *Refining of* SUGAR.

SUGAR, *Royal*. The baſis of this ſort ought to be the pureſt refined ſugar to be found. This they melt with a weak lime-water; and, ſometimes, to make it the whiter, and prevent the lime from reddening it, they uſe alum-water. This they clarify three times, and paſs as often through a cloſe cloth, uſing the very beſt earth. When prepared with theſe precautions it is whiter than ſnow, and ſo tranſparent, that we ſee a finger touching it, even through the thickeſt part of the loaf.

The curious in the whole art of ſugar-making, or the reducing vegetable juices to what we call ſugar, by expreſſion, decoction, clarification, graining, claying, and cryſtallization, will find farther accounts and directions, in the ſeveral proceſſes of this art, in Piſo's Hiſt. Ind.; in Angelus Sala's Saccharologia; in Dr. Slare's Treatiſe on Sugars; in Sir Hans Sloane's Hiſtory of Jamaica; Baker's Eſſay, above cited; and Edwards's Hiſtory of the Weſt Indies, vol ii. There are alſo ſeveral valuable papers on theſe ſubjects in the Philoſophical Tranſactions.

SUGAR, *Refining of*, is the art of purifying ſugar, and of giving it a ſuperior degree of whiteneſs and ſolidity. The excellence of muſcovado ſugars, or ſuch as have not been refined by the planter, but are ſent home in the moſt crude ſtate, conſiſts in their whiteneſs, dryneſs or freeneſs, cleanneſs and ſharpneſs, or ſtrength. The judicious refiner decides upon theſe ſeveral qualities by the eye, the touch, and the taſte.

The firſt operation in the proceſs of refining is that of *clearing the pans*; previouſly to which they are charged, by throwing about ſix quarts of freſh bullock's blood (called *ſpice*) into each pan, and filling it with lime-water to about half the height from the bottom to the part in which the brace is fixed; and when theſe are well ſtirred together, the pan is filled to the brim with raw ſugar. This maſs, with a moderate fire, will in about two hours be brought to the verge of boiling heat; but it ſhould not be allowed actually to boil; and in this time the earthy particles of the ſugar, and other adventitious impurities, will be ſeparated from it by the effect of the heat, and the cleanſing quality

of the ſpice, and thrown up to the ſurface. About two quarts of ſpice are added to each pan, within the firſt hour after the fires are lighted. The ſcum thus produced, which is uſually from four to ten inches thick, is fit to be taken off, when the ſurface appears black and dry, and not greaſy; and it is gently removed with a broad ſkimmer into a portable tub, and conveyed into the ſcum-ciſtern. Having done this, the panman ſtirs together a ladleful of ſpice (*e. gr.* about a quart), and a quantity of lime-water (*e. gr.* one or two gallons, as the caſe may require); and pours this mixture into each pan. When the ſugar is again brought to a ſcalding heat, it throws up a ſecond ſcum, not ſo foul as the firſt, which is removed as before. He then adds a freſh quantity of ſpice, but leſs than the former, and repeats this operation, till the ſugar caſts up a clean milky froth, which indicates that the impurity is wholly extracted. The liquor is alſo ſometimes examined with a bright ſilver or metal ſpoon, that any remaining foulneſs may be diſcovered. In the making of double loaves, powder loaves, or very fine ſingle loaves, it is uſual to heighten the natural colour of the ſugar by the addition of a little blue. For this purpoſe, when the pans are almoſt clear, the quantity of about ſix pennyweights troy of the fineſt indigo, finely powdered and filtered through a piece of woollen or blanketing in a baſon of freſh water, and well ſtirred together in a baſon, is thrown into each pan. The ſugar being once raiſed in the pan after this infuſion, the groſſer particles of the colour are taken off in the laſt ſcum, and the remainder is incorporated with the ſugar in the pan.

The panman having brought the ſugar to the cleaneſt ſtate, prepares to *ſkip it off*, or to ſhift it from one veſſel to another: this is done by means of a wooden gutter laid along the parts, and opening into the clarifying ciſtern. Over this ciſtern, upon large iron bars, is fixed an oblong baſket, about ſixteen inches deep, in which a large thick blanket is faſtened; and through this blanket and baſket the ſugar liquid paſſes out of the gutter; and to the maſs a quantity of ſyrup is uſually added. Having meaſured the quantity of liquid in the ciſtern with a rod graduated by inches, the panman pumps back into the pans either the ſixth or ninth part of the whole, as he is directed by the ſupervifor or boiler; and the pans are all ſupplied together by means of a trough. When this is done, the fire is ſtirred up to a conſiderable degree of fierceneſs; and then commences a new operation, *viz. evaporation*. In this part of the proceſs (the day's work being divided into three fillings), the panman pumps into the pan one-ninth part of the quantity in the ciſtern, which in a few ſeconds begins to boil, and muſt be continued in a boiling ſtate, but not with too intenſe a fire; and to prevent the ſugar from boiling up to the ſurface of the pan, or from boiling over, he caſts a ſmall quantity (*viz.* a piece as large as a nutmeg or walnut, as the caſe may require) of butter or greaſe into the boiling liquor. Here it is to be obſerved, that ſugar ſhould boil low in the pan, and yet not too flat, like water; for by riſing hollow from the bottom, the neceſſary evaporation is retarded, and the ſugar is expoſed to the action of the fire for a longer time than it ought to be. In a ſpace of time from twelve to thirty minutes, the evaporation will have produced its effect, and the ſugar acquire the requiſite degree of viſcouſneſs. The ſtate will be indicated by various circumſtances; as by the bubbles dragging heavily over the ſurface of the boiling maſs, and by the clammy liquid falling in ropes from the proof-ſtick; but principally by that teſt which is called the *proof*. For this purpoſe the boiler draws the ſtick out of the boiling liquid with his right hand, and placing his left thumb upon the ſugar, draws it acroſs the ſtick, carrying away upon the end of his thumb as much of the ſugar as will hang upon it; he then, by means of a candle placed in a black box, called the proof-box, and by repeated trials (drawing the ſugar to a thread between his thumb and fore-finger) determines when the evaporation is complete; and when this is decided, the fire is ſmothered, and nearly quenched. The hot ſugar-liquor is then removed by means of baſons out of the pans into coolers, two or three gallons being left in each pan to prevent the bottom from being ſcorched; and the pans are again ſupplied with a quantity of liquor for the next evaporation. The liquor in the coolers is gently ſtirred to prevent a cruſt from forming on its ſurface. When the ſecond quantity is brought to proof, and ſkipped off into the coolers, the pans are ſupplied with a ſimilar quantity; and while this is boiling, that part of the proceſs of refining, called *granulation*, is purſued. For this purpoſe the ſugar is diſturbed in the coolers by an inſtrument called an *oar*, and reſembling the oar of a boat: the violent motion thus continued for ſeveral minutes, ſerves to deſtroy the viſcouſneſs of the ſugar, and to complete the granulation. Upon this operation much of the beauty and ſucceſs of the manufacture depend; for if the ſugars are not ſtirred enough, the grain of the refined ſugar will be large and looſe, and its colour not ſufficiently white; but if it be ſtirred too much, the grains will be broken, the ſugar will be diſunited in its parts, and though cloſe and ſmooth, without luſtre; and it will loſe conſiderably of its due weight. When the third ſkipping is boiled, and the coolers ſufficiently ſtirred, the contents of the pans are removed to the coolers, as before; and thus the firſt ſtage of boiling for the day is completed. The courſe of the other two fillings is preciſely the ſame.

The next operation in refining is conducted in that part of the ground-floor of a ſugar-houſe, which is denominated the *fill-houſe*, becauſe all the upper floors of the houſe are to be filled from this; and this operation conſiſts in *filling* the moulds with the three ſkippings contained in the coolers. The moulds, in the form of inverted cones, previouſly prepared by ſoaking and waſhing them, and ſtopping their apertures with wet linen rags, are placed ſide by ſide, and in rows two or three deep: their number is to ſuffice for the quantity of liquor in the coolers, which is eſtimated by the number of baſons which were ſkipped off from the pans; and they are propped up by other moulds (commonly ſuch as are broken) placed with the broad end downwards, in front of the outward rank, by way of abutment: theſe are called *ſtayers*. The ſugar, being previouſly ſtirred in the coolers, in order thoroughly to mix each ſkipping, is ladled out of the coolers in ſucceſſion, and not all at once, (unleſs the fillings are ſmall, in loaves, and always in lumps,) into baſons conveniently ſituated; and theſe are carried into the fill-houſe, where as much of the ſugar is poured into each mould as will fill about one-third of its capacity; the ſame quantity is again poured into each; and at the third time they are filled to the brim.

The moulds being filled, the next operation, which is that of ſtirring the ſugar in them, is called *hauling*, and is deſigned to prevent an adheſion to the mould, and to lay the grain of the maſs even and regular through all its parts. In this buſineſs each man takes a tool, made of wainſcot, and called a knife, and in ſize proportioned to that of the mould to be ſtirred; with this tool, keeping his hand over the centre of the mould, he ſcrapes the ſugar from its ſides by ſucceſſive ſtrokes downwards, carried all round; and when two revolutions are performed, the ſugar is allowed to reſt ſome minutes, until it has acquired ſome firmneſs. The moulds,

being ftirred round three or four times, according to the direction of the boiler, are no more difturbed till they are pulled up.

The procefs already defcribed relates to fugar *once refined*, called fingle loaves: double loaves are ufually cleared with the whites of eggs inftead of fpice, (two hundred of which are neceffary to each pan,) and with frefh water inftead of lime-water. With refpect to the proof, one rule only can be laid down; *viz.* the fugar muft be boiled higher as the moulds which contain it are increafed in fize.

The order of refining is uniformly this: to begin the firft day with the fineft fugar intended to be wrought, and to proceed daily with fugar of a lower quality, and of courfe to begin with fmall loaf-moulds, and to ufe larger moulds progreffively; fo that the brownifh fugar will be put into large lump-moulds; for this fugar works beft in large maffes, and it is likewife more in demand in England than the finer kind. The ufe of this diftribution of a refining is to enable the boiler to make a more advantageous difpofition of his fyrups and fcums. The order of the firft twelve days is ufually as follows: firft day, double loaves; fecond and third days, powder loaves; fourth, fifth, and fixth, fingle loaves; feventh, Pruffian lumps; eighth, Canary, or pattern lumps; ninth, tenth, eleventh, and twelfth days, large lumps. To thefe twelve days are added four or five more, in a part of the procefs called *baftard-boiling;* and thefe fixteen or feventeen days conftitute a complete feries, denominated a complement, or refining.

From this digreffion let us now return to the fill-houfe; where the fecond and third fillings having been boiled off, and paffed from the coolers into the moulds, in the manner already defcribed, the panman proceeds to make over the fcum which was taken off the pans in the morning, in order to extract the remaining fugar from it; the method of doing this will be hereafter explained. When it is finifhed, the pans are loaded for the work of the following day. In the evening, when the new-made goods are cool, and fit for removal without damage, they are pulled up into that floor of the houfe which is beft fuited for receiving them, and where a proper number of well-forted pots are placed in ranks for this purpofe. The up-ftairs man plucks out from the point of every one the ftopper or rag; and pricks them in the point with an awl, the fize of which is proportioned to the mould; and they are then fet upon the pots.

The contents of the moulds, cleared by the preceding operations of their earthy particles and water, confift of the vegetable falt, and an oily matter, now called *fyrup*, but which, after the final extraction of the falts, will be called *melaffes*. For the feparation of thefe there is required a feries of operations, which may be diftinguifhed by the name of *filtering*, or *draining*. In twenty-four hours after the loaves have been placed upon the pots, the quantity of fyrup which will have exuded from the aperture of each, will fill more than half of the pot on which it ftands. When the ftate of the loaves has been examined, by drawing one or two loaves of each filling out of their moulds, if the fyrups are not in a digefting ftate, they are left unclayed for two or three days longer, and the warmth of the room in which they ftand is fomewhat increafed; but if they manifeft a proper appearance, they are prepared for receiving the firft clay, which is laid on either the next or the third day. The green new-made loaves are judged to bear a healthy and promifing appearance, when the fyrups have quitted the broad part of the loaf, and are evenly drawn together; and when the whole furface has a compact and fmooth appearance, they are fit to receive clay. When the fyrup hath fcarcely defcended from the top or face of the cone; when the head, *i. e.* the narrow and moift end, is not evenly drawn off to a line; it is concluded that the fugar is over-boiled, or of an ill quality; the fyrups are not in a ftate of digeftion; and time is given, and heat added, to make them fit to receive the clay. On the other hand, if the moifture is fhrunk and fettled, and of a pale colour juft round the apex of the cone, there is reafon to apprehend that the fugar is under-boiled, or too free; in which cafe the furface or coat will appear loofe, and want that fmoothnefs which the well-boiled loaves exhibit. When this is the cafe, they muft be lightly clayed, and care muft be taken that the clay be not too thin or wet. Before the clay is laid on, the thin cruft, which had been formed round the edge of the mould by the motion of the hauling knife, is fcraped from each loaf into the receiving box, and by preffing the face of the loaf with that part of the hand which is neareft the wrift, a fmall concavity is made for receiving the firft clay, as well as a proper folidity to the bed on which it is intended to reft.

The firft or green fyrup is now taken away, and poured into large earthen jars, called *gathering-pots;* and the empty pots are returned to receive the moulds which had been taken from them. When they are returned to their proper places, a fmall ladleful of wet clay is poured on the face of each loaf. This firft or green clay dries up in five or fix days, and forms a cake, which is taken off, and laid by for future ufe. When the clay is removed, the whole furface of the loaf will be found to have fhrunk under it, and the loaf is become concave in the middle. With a tool, called a *bottoming-trowel*, the fugar which adheres to the fides of the mould is cut away by a horizontal movement: and a fmall quantity of fcrapings, or of lumps broken down for this purpofe, is added to the loofe fugar which the trowel had cut; and they are preffed down together on the furface, till the whole has been brought to a good level, and to a moderate degree of firmnefs for bearing the next clay.

On the following day the loaves are clayed a fecond time; and when this clay is dry, it is removed, like the former; and each loaf is drawn out of its mould, and carefully examined; and this part of the procefs is called *overfeeing*. Double loaves, fine powder loaves, and fine fingle loaves, will fometimes, under this clay, be found *neat, i. e.* the rednefs or brownnefs will have quitted the loaf, and the head, though ftill moift, will appear perfectly free from difcoloration. The workman, however, in order to be farther fatisfied, cuts off the heads of two or three loaves with the trowel; and if he is fatisfied, thefe loaves are to be clayed no more; but he proceeds to the operation of *brufhing-off, i. e.* of fcraping off the irregularities and impurities occafioned by the contact with the clay with an iron tool, called a *brufhing-hook;* and with one corner of this a number or letter is fcratched upon the level face of the loaf. To thofe loaves which are not found neat, the workman gives a third clay; which is ufually laid on in a thinner mafs than the former. If his loaves are not yet quite finifhed, he puts a little frefh moifture on the back of the overfeen clay, and thus effects his purpofe.

The loaves being now rendered neat, and brufhed off, muft ftand fome days in the moulds to acquire *face*, or that ftony hardnefs of furface, which will enable them to ftand firm, when they are turned down out of the moulds; and during this time they are once or twice loofened in the moulds by a gentle blow on a ftool, or againft a poft; and thus the coats are improved by preventing adhefion to the moulds, and facilitating the precipitation of the remaining moifture. The

windows are opened to let in air, if the weather be dry; and the points or nofes are alfo examined, which will fometimes melt away, whilft the above operation is effecting. When thefe fymptoms appear, the workman proceeds to turn down his loaves, by taking the moulds from the pots, covering the floor with clear brown paper, and turning each loaf down with its mould over it. They are ufually turned down either upon the ftove-head, or in fome warm place, becaufe by being left uncovered, and expofed to the action of cold air, the moifture remaining in the head will not defcend into the body of the loaf, and be equally difperfed; but remaining in the head, would fpoil and disfigure the loaf; partly by the fyrup's coagulating, and becoming unfit to defcend between the fine interftices of the concrete body, and partly from the aftriction of the folid particles. With thefe precautions, in twenty-four hours the moifture is apparently difperfed, and the cone affumes throughout an uniform appearance. The loaves are then taken off the floor, feparately examined, and cleared of any difcoloured fpecks with a fmall knife; and are either papered and fet in the ftove, or elfe are placed in the ftove without paper, as the cafe may require. If any of them have ftill a remaining yellownefs in the head, the point is cut off, and they are then called *fpot-loaves*. They remain in the ftove five, fix, or feven days, till they are entirely dry, and are then fit for fale and ufe. The management above ftairs in the courfe of this one day's work is nearly the fame, whether the fugar be fine or coarfe.

Brown fugars, wrought in large moulds, require more clay than fine fugars in fmall moulds: nor is it neceffary that lumps fhould be made neat; but it is the conftant practice to cut off the wet head from every lump, fo as to leave no remaining rednefs; thefe wet tips, called *lump-headings*, are received into a large mould, and placed upon a pot to drain, and when dry, are melted for making double loaves, or for improving powder loaves; or elfe they are bruifed and mixed with brufhings to *bottom-up*, *i. e.* to defend the face of loaves, or other goods, before they receive clay. Large lumps frequently need claying four times. And it may be obferved in general, that fugars of every kind require more heat to bring them forward, as they fink in quality.

The materials for double-loaf boiling are made from refined fugar, and frequently from loaves or lumps bought for that purpofe. But thofe who are moft curious in this fabric, chufe to make lumps for this purpofe, which are called *melters*: they are low boiled, and ftirred but little (though fome boilers ftir them much), in order to preferve the ftrength of the fugar unimpaired. Fine double loaves are kept in a room of the temperature of a common parlour; a little warmth is fufficient for powder loaves, and fine fingle loaves; inferior loaves, and lumps of a middling quality, require warmth; but the browneft lumps and *baftards* thrive in a glowing heat. Every fort of refined fugar will bear and require more heat in proportion as it is higher boiled; for the brown fyrupy matter will not quit the denfer, unlefs it be kept in a fluid ftate; and this can only be effected by the action of heat; and, moreover, the fluid parts of high-boiled goods muft be more vifcous than thofe of goods which have been lefs bound up by fire.

The fyrups, which are difcharged from refined fugar during the operation of draining, exceed in bulk and weight the whole quantity of loaf or lump fugar, and are, therefore, of great importance in this manufactory; and upon the proper management of them much of its fuccefs depends. It will be proper, therefore, to purfue the enquiry relating to the ufe of fyrups, produced from a day's work of fugar once refined in loaves. When the loaves are prepared to receive the firft clay, the fyrup is collected into gathering-pots, each of which contains from 50 to 60 pounds of fyrup; this is called *green* fyrup, on account of the new or green ftate of the loaves from which it runs; and the quantity of it is ufually about 15 gathering-pots from each pan of goods. The next fyrup, called *fecond runnings*, is commonly collected when the fecond clay is removed, and amounts in quantity to about eight gathering-pots *per* pan. The third and laft collection is made after the moulds are finally removed from the pots; it is called *drippings*, and is about five gathering-pots *per* pan. However, fome workmen collect their fyrups oftener than thrice. The fyrups of every kind of refined fugar increafe in finenefs and value, the later they exude from the moulds. As for the appropriation of them, the green or low fyrups are boiled away on the days next after the conclufion of refining: they are taken into the pans without the addition of any fugar, and after a fufficient evaporation are poured into large moulds; and under the name of *baftard* fugar, form a principal article in the fugar-trade. The finer fyrups are all incorporated with fugar, and a proportion of them is daily brought down through the fyrup-pipes into the ciftern, at the fame time in which the fugar is firft fkipped from the pans; the fyrup-pipe difcharging its contents into the clarifying bafket, fo that the fyrup, as well as the fugar, paffes through the blanket; and it is pumped back from the ciftern into the pans.

The following eftimates exhibit the quantity of fyrup that may be allowed (*cæteris paribus*) to a given quantity of fugar; *viz.* for double loaves, fix gathering-pots *per* pan; for powder loaves, 10 ditto; for fine fingle loaves, 15 ditto; for middling loaves, 20 ditto; for brown fingle loaves, and Canary lumps, 25 ditto; for lumps, 30 or 40 ditto.

With the neceffary allowances for particular circumftances, the feveral forts of fyrups may be duly appropriated in the following manner. Green fyrups of every kind may be mixed with raw fugar, or applied to the making of goods, two degrees in quality lower than thofe from which thefe fyrups were produced. Second runnings of every kind are fit to be incorporated with goods one degree below thofe from which they were produced. Drippings may be ufed with raw fugar, or with other proper materials, in making the fame kind of goods from which they had been fupplied. In other words, the green fyrup of double loaves would be ufed in making fingle loaves; the fecond runnings would go into the compofition of powder loaves; and the drippings would enter into the fubftance of other double loaves. Again, the green fyrup of large lumps would be boiled off in *baftards;* the fecond running would make *pieces;* and the dripping, added to proper fugar, would be united therewith in the production of other lumps.

Pieces are a better kind of baftards, which are either boiled from fyrups that are too good to make baftards, or are made of fuch fyrups, and a fmall portion of cheap and bad fugar, which is too poor to make lumps. In the latter cafe, they are called *fugar-pieces;* but in either, all the fyrup that comes from them is boiled again, either to make baftards or other pieces, according to its goodnefs; whereas the fyrup that runs from baftards is always confidered as a caput mortuum, and no efforts are made to obtain any fugar from it, but it is put into cafks, and fold under the denomination of melaffes. It is, therefore, worth the boiler's attention to keep all the weight of fugar poffible in his baftards; and for this purpofe he boils them as high as he may venture, without incurring the danger of making ftopped baftards, *i. e.* baftards from which the melaffes

will not run; which may be owing either to the ill quality of the materials, or to overboiling. But as the fyrup of pieces is to be boiled again, a good workman never exhaufts it by overboiling. The materials of which baftards and pieces are compofed, not abounding with falts like thofe already treated of, have not an equal difpofition to concrete; and, therefore, it is found neceffary to give them fome aid, in order to effect the neceffary granulation: this is done by taking *grain* (which we fhall prefently explain) into the coolers. Thefe inferior productions are ftirred, neither in the coolers nor in the moulds, any more than by a fmall movement round the coolers, with an iron fcraper, juft fufficient to incorporate the grain with the hot fluid mafs.

In order to illuftrate the formation of this grain, we may obferve, that the ftrong particles of fugar, which are capable of concretion, have evidently a greater degree of denfity than the oily or aqueous. When the hot fluid is poured into a baftard or piece mould, thefe denfer particles defcend, and would pafs into the pots if there were any paffage for them; but the ftopper is not taken out of the moulds of thefe goods until five, fix, feven, or eight days after they have been pulled up; for they want time to harden, and cannot fafely be left unftopped. Having reached the lower part of the mould, they are formed into fmall ftony fubftances of the nature of candy, and when the ftoppers are withdrawn, thefe fmall ftones remain near the point of the mould, and form what is properly called *baftard grain*.

Baftards and pieces are ufually clayed but twice, and when dry enough, are knocked out of the moulds, their wet heads being cut off into a large mould placed to receive them, and they are called *baftard-heading*, or *fmear;* in another mould is preferved the grain, which ufually forms a ftratum about two inches broad, beginning about four inches from the point of the mould. The baftards and pieces are then put into the ftove, and in five, fix, or feven days, will be found dry enough; for they muft not, like lumps and loaves, be rendered perfectly dry. They are then taken out and piled in a room, as near the mill as poffible, and ground all together; or the brown tip is cut off, and the other two parts, called the *middle* and *face*, are ground together: or fometimes the baftard or piece is divided into three parts, which are ground feparately, and fold at different prices.

We fhall now clofe this article with a fhort account of the method of making over *fcums*, and the application of their produce. The refiner extracts from the fcum of his fugars, every particle of fugar which it is in his power to obtain; and after he has reduced the fcum to fuch a ftate that it appears to be a mere earth, refembling garden mould, he fells it to a fcum-boiler, who again tries it over the fire, and extracts a fmall quantity of fweet liquor out of it. The fcum of fine treble or double loaves is often put into the pans again without any procefs, and mixed with raw fugar, for the production of inferior goods: but, in general, the fcum of each day's work is made over in the fame day after the boiling of the fugar is finifhed. The method is this; the panman, having put about three quarts of fpice into his pan, draws lime-water until the pan be four-fifths full without the pan-brace; to this he adds about four tubs of the fcum, each tub containing about three-fourths of a hundred-weight. Having ftirred the liquor well, he makes a moderate fire, and the fcum will feparate from the fluid and float upon the top of it: with a fmall iron fcraper he prevents any foulnefs from adhering to the bottom of the pans; and then fuffers the fire to increafe, and the liquid, upon the verge of boiling, is feen through the openings of the dirty furface. Having kept it fimmering for feveral hours, and having provided a cooler or receiver, over which is placed a ftrong wooden frame, and upon this a bafket, to which a coarfe bag, called the *fcum-bag*, is fitted, he pours the contents of his pan into this bafket and bag; and then the mouth of the bag is drawn up, and well twifted together, and a ftrong board, called a *fcum-board*, is laid upon the bags, with feveral weights upon the board, to prefs down the fcum. In the fpace of an hour, or an hour and a half, the bag fhould be twifted and preffed; and the liquor, which oozes plentifully through the bag, is ufually taken into the pans the next morning: its thinnefs renders it ufeful in clearing the pans, and if any grofs matter hath paffed through the bags, it is drawn off with the reft of the fcum of the fugar when cleared. The fcum, as it is taken from the pan, is called *fat fcum*, and the liquid matter drawn from it bears the fame appellation; in contradiftinction to the poor meagre liquor which is expreffed from the fame fcum when they are made over a fecond time, by an operation much like the former. After preffing and draining, the exhaufted remains, under the name of *rubbifh fcum*, are either burnt in the cockell, or delivered to the fcum-boiler at a very low rate. The produce of over-made fcums muft be ufed immediately, or it muft be fhortened, *i. e.* boiled thick; otherwife it will turn four and do great harm; for acidity is a conftant enemy and deftroyer of fugar.

The liquor drawn from thefe fcums is commonly ufed in baftard boiling, or in the browneft lumps. There is a large proportion of the fat fcum ufually left of every refining, to be made over during the baftard boiling: it is common to fet by the firft or groffeft fcum for this purpofe, and to keep feparate the finer and later fcums, which are made over day by day in the manner already defcribed: the liquor thus obtained from the fat fcums, being full of fugar, is very ufeful to the baftards, fortifying the fyrups, and promoting their ftrength and adhefion. The editor is indebted for the materials which have fupplied this article, and thofe on the manufacture of fugar-candy, and the conftruction of a fugar-houfe, to the kind communication of Mr. Griffin, an eminent fugar-refiner in London.

Of the improvements that have been made in the proceffes for refining of fugar, we fhall give an account according to the order of time in which the patents were granted.

In October 1812, Edward Charles Howard, efq. of Weftbourn Green, in the county of Middlefex, obtained a patent, the fpecification of which informs us, that he has eftablifhed and adopted the following operations. In the firft inftance, he fubmits raw or mufcovado fugar to a primary operation, by well mixing, as expeditioufly as poffible, the faid fugar with fuch a quantity of water as will, at the common temperature of the atmofphere, bring it to a magma of the confiftency of well-worked mortar: having left it at reft for the fpace of an hour or more, he heats it to a moderate temperature, *e. g.* from 190° to 200° Fahr., which is moft conveniently effected in a veffel furrounded by boiling-water or fteam, under the common preffure of the atmofphere; he then adds more fugar, or a thinner magma, fo as to render the mafs imperfectly fluid, and fills the moulds with it from the water-bath; and when it is become cold in the moulds, he takes the ftopper out of the mould, and fuffers the melaffes to drain from it. When the drainage is completed, he pares down the large or upper furface of the lump, loaf, or mafs of fugar remaining in the mould, with any fit inftrument, until the fugar prefents an uniform appearance. He next mixes the fugar fo pared off with

cold water, till the magma acquires a confiftency, which will not allow it to readily clofe behind the ftizar; and then replaces it, in that condition, upon the uniform and firm furface before prepared; and as foon as the magma becomes moderately dry, he pours upon it, with the intervention of a float or fimilar guard, a cold faturated folution of fine fugar in cold water, about half an inch deep; or, he takes off the faid magma down to the furface of the lump, loaf, or mafs, left after the firft paring, and remixes the fame with water to a thinner confiftency than laft-mentioned, and again replaces it as aforefaid; and he repeats the faid operations by this magma, or with a cold faturated folution of finer fugar than that which he intends to refine, according to its nature or quality. He farther declares, that when the fugar proves extremely clofe-grained, and the furface extremely hard, an unfaturated folution of fugar, or even water itfelf, may be poured on it, without running in: but this procefs requires too much nicety for general practice. When the fugar proves open-grained, the finer the fugar, made into magma, is ground, the better, becaufe the moifture is thereby prevented from defcending too faft or unequally into the loaf. It is not neceffary, that the fugar taken from the furface of the loaf fhould be ufed as magma or fyrup upon it.

The fit time for terminating this primary operation is afcertained either by drawing from time to time one of the lumps, loaves, or maffes fo prepared, or by obferving the greater or lefs freedom with which new moifture is admitted, and the colour of the melaffes dripping out. It is farther declared, that it is moft beneficial in conducting this procefs, to leave the temperature of the place or apartment in which the moulds are placed, previoufly to their being treated with the magma, to about 60°, and again to raife the fame to about 80° or 90°, after the furface of the loaf becomes dry for the laft time. It will be neceffary, in every cafe of the percolation of melaffes or fyrup, to pierce, perforate, or break the dry furface of the mafs of fugar in the moulds, when it is become fo folid or iced over as to prevent the accefs or efcape of the air into or out of the fugar, and thus to impede or prevent the flow of the melaffes or fyrup.

This primary operation being finifhed, the operator does in the ufual manner break or draw out the lumps, loaves, or maffes, and feparate the net or good fugar from that which retains melaffes, referving this latter to be mixed up with raw fugar, for a fubfequent preparatory operation, fuch as has been already defcribed. The former is then refined by pouring upon it, in any convenient veffel, 6lbs. of water (boiling-hot) to every 5 lbs. of fugar, deducting about 6 *per cent.* for the moifture previoufly contained in it; and having infured a perfect diffolution of the fugar, by ftirring, the impurities are allowed to fubfide, and then the folution is drawn off from the faid impurities into another clean fuitable veffel; and in order farther to clarify and feparate impurities and colouring matter, the ordinary finings are added. Thefe finings are prepared by flaking well-burned lime with boiling water, fo as to obtain a cream of lime; to this is added about an equal bulk of water, and the mixture is boiled for fome minutes, until the lime affumes the appearance of fine curd: the extraneous matters or lumps, always contained in lime, are feparated by wafhing over, or, as the chemifts term it, by the procefs of elutriation; and that this may be done effectually, the lime and liquor fo wafhed over, are made to pafs through as fine a fieve as will admit the paffage of the fineft curds. The next part of the procefs is to diffolve about 2½ lbs. of alum for every cwt. of folid fugar that is to be refined in about 16 times its weight of water, and to add to fuch folution about 70 or 80 grains of whiting for each pound of alum; and after ftirring up the mixture till the effervefcence ceafes, the fufpended fubftances are allowed to fubfide, and the folution is drawn off from the precipitated matters, and then are put into it the prepared lime-curds, fhook up with the water they retain (the whole being agitated during the effufion) in fuch quantity of the curds, fo that paper ftained with turmeric fhall barely change its colour by immerfion in the mixture, and fhall recover its former yellownefs when dry, and fhall, by immerfion in the clear fupernatant liquor, after fubfidence, be fcarcely changed at all. The finings, thus duly prepared, are fuffered to fettle to the bottom of the containing veffel; and after draining off the fupernatant liquor, the faid finings are placed upon blankets, fupported in the manner of a filter, and the moifture is drained off till the mafs begins to contract, and feparate by cracks in it; and in this laft ftate the faid finings are fit for the clarification of the fugar laft drawn off, as above defcribed. Such a quantity of that folution, or of any other fimilar folution of fugar, is added by degrees, and with ftirring, as will bring them to an uniform creamy ftate. This mixture is then poured into the whole quantity of the faid folution of fugar prepared or intended for clarification as aforefaid, with fufficient agitation for diffufing the finings equally.

The refined or clarified fugar is then fuffered to remain, either during the night, or for about fix hours, and the bright liquor drawn off from the finings, in the ufual methods; and an evaporation is commenced and carried on at the temperature of about 200°, which is beft effected by the heat of fteam, or water under the common preffure of the atmofphere, until the hot liquor fhall have acquired a fpecific gravity of about 1.37 (that of water being 100), and in this ftate the fame is transferred to any convenient veffel, and ftirred frequently, until it affume the proper granular confiftence to fill the moulds, and accordingly the moulds are filled with it. The ftoppers are then taken out from the moulds as foon as they become cold, and the fyrup naturally contained in the lump, loaf, or mafs, is allowed to run off from it in the ufual manner: during the faid operation, and when the fyrup has left the upper furface of the lump, loaf, or mafs, the fame is pared down, as before defcribed; and if the fugar appear fufficiently fine for the intended confumption or market, it is taken out of the mould, after it ceafes to drip, in the ufual manner, the fmaller end of the loaf not clear of fyrup being cut off; and it is then dried in the ordinary mode. But if the lump or loaf be not fufficiently white, the fugar before pared off the furface is mixed up to a magma with water, as in the primary operation. If the loaf, as above prepared, be not fufficiently denfe or clofe in its grain to fatisfy the confumer, the loaf, previoufly to drying, is remoulded, according to the ufual practice, by ftamping the grains into a metallic or other mould, which will immediately redeliver the fame. If it be required to retain the point of the lump, loaf, or mafs, without returning the fyrup contained in that point upon its body, this defideratum is effected by the appendage of a pipe, applied and fixed to moulds of the ufual conftruction, having the aperture enlarged to one inch at the leaft, or to form part of a new mould, which is to be fabricated on purpofe; then the lower portion of the fugar is taken off, which will be contained in the faid pipe, along with the redundant fyrup, inftead of taking off the point as ufual.

To the firft of the liquors left in the two cifterns or other veffels which contain the infoluble impurities, is added about its bulk of boiling water, and it is then paffed through

a cloth sufficiently close in its texture for retaining the gross impurities; and the second liquor, containing the above-described finings, is added, abstracting from them, by washing and subsidence, all the sweet they contain; which sweet liquor is used for magma. The syrups, which drain from sugars which have been subjected to the action of finings, may be evaporated without any addition, provided the boiling temperature be avoided by means of the steam or water-bath above-mentioned; and such syrups will, by such treatment, afford strong crystals a second, third, or even fourth time. Or, otherwise, sugar remaining from top-parings, cut-off points, or any other remnants, may be melted in them, upon the water-bath, to bring the same up to their crystallizing density or granular consistency: and the inferior syrups may be advantageously mixed with muscovado sugar instead of water, in the manner stated in the account of the primary operation.

The lumps, loaves, or masses of sugar which have been refined by the use of the ordinary or common finings, or any other sugars in a forward state of refinement, may be farther refined by the application of other finings, prepared in the following manner; *viz.* by dissolving about three pounds and a half of alum for every hundred weight of solid sugar, in about sixteen times its weight of boiling-hot water, and adding to such solution about seventy or eighty grains of whiting for each pound of alum; and after stirring up such mixture till the effervescence ceases, allowing the suspended substances to subside, and drawing off the solution, pouring into it (instead of the lime-curds in the ordinary finings) a concentrated solution or ley of caustic soda, until the agitated mixture shall produce a very slight stain upon turmeric paper; and then adding to it the fairest water, washing the precipitate by alternate diffusion and subsidence, until the water comes off tasteless, and then drawing off or draining the remaining water from the finings, as before described. The water is often purified by the well-known process of boiling it with a small quantity of alum, and a little lime or chalk, taking care to leave no excess of caustic lime in solution. It is observed, that a compound of lime and alumine would answer the purpose of the first finings, and that pure alumine, howsoever obtained, will answer the purpose of the second finings: and that caustic lime is preferred to potash, because the salt resulting is most easily washed away, and to ammonia, because this last is an article of great price. In the specification it is added, that the superior degree of refinement in solid sugar (already refined to a forward state) is produced by dissolving the sugar intended to be refined, in the fairest water (boiling hot), in the manner and proportion already described. Subsequently to his preparatory operation, and immediately upon the solution being effected, the patentee mixes and diffuses his second finings as the first finings were directed to be mixed and diffused, and after due clarification by repose, he proceeds to the evaporation and subsequent completion of the sugar in loaves, as before directed and prescribed in like cases. He farther declares, that in the application of heat to the refining of sugars, he makes use, in certain circumstances, of higher temperatures than those stated (although less beneficial), taking care to preserve an uniformity in the application of the heat to the surface of the boiler. For temperatures above the boiling point of water, he makes his steam-bath strong, and capable of being properly closed, and provides the same with a feeder under due pressure, or a forcing-pump for feeding, and a safety-valve and pipes of communication, cocks, and gauges, and all or any of the needful fittings-up, which are commonly used with steam-boilers. It is farther remarked, that if it be required to use the ordinary or common finings to very coarse moist or deliquescent sugars, it will be necessary to add a greater proportion of the lime-curds than that which has been prescribed with regard to sugars partly refined by percolation or otherwise; and making the said addition, the judgment of the operator must be directed by the quality of the said coarse moist or deliquescent sugars. The patentee further declares, that his invention, and the several manipulations of it, may be practised, wholly or separately, without or in conjunction with the methods of refining sugars already in common use. Mr. E. C. Howard obtained another patent, dated Nov. 20th, 1813, for certain improvements in the processes described in the patent granted to him October 31st, 1812, and certain apparatus for carrying the same into effect.

A patent, dated May 8th, 1815, was granted to Peter Martineau the younger, of Canonbury-House, Islington, and John Martineau the younger, of Stamford-Hill, gentleman, for a new method or methods of refining or clarifying certain vegetable substances. In their specification they declare, that if their invention, so far as relates to animal charcoal, be applied to vegetable acids, such as are usually prepared or manufactured in a crystallized state, or other vegetable substances, the process should be the same as is hereafter described, excepting only that as blood may be advantageously used in refining sugar, it is not necessary for refining other substances, from which the articles which they employ may be separated by filtering in common and well-known methods.

The articles employed by the patentees for purifying and clarifying sugar, are, 1st, animal charcoal; that is, animal substances, properly burnt, or charred, or calcined, such as ivory-black, bone-ash, &c. and afterwards reduced into smaller pieces or powder. 2dly. Bituminous earths, commonly called coals, either in the state in which they are mined, or articles of their products after fusion, and reduced, as before-mentioned. 3dly. Certain argillaceous earths, known by the name of ochres. 4thly. The vegetable charcoal, usually called lamp-black. The first-mentioned articles, however, are preferred in the process of refining and clarifying sugar, which render the sugar so clarified much whiter than by the heretofore common method of clarifying. The following method of applying the above-mentioned substances is preferred. We charge, say the patentees, or fill our boilers or pans with sugar and water, or lime-water, as in the common and well-known methods of refining sugar, only sometimes preferring to add a little more water or lime-water than in the common mode of refining, as it generally more easily and effectually separates the animal charcoal, or other substances, from the liquid sugar. And we also add to the above sugar and water in the boiler the substances before-mentioned, in any quantity, according to the quality of the sugar to be refined or clarified; though we generally prefer from two to five pounds of charcoal or earths before-mentioned, to and for every hundred weight of sugar to be refined or clarified. And, farther, we pour into the boiler the usual finings of eggs, blood, or other albuminous matter, in rather larger quantities than in the usual mode of refining, in order, in some degree, to coagulate and combine the animal charcoal, or other substances, with the dirt contained in the sugar. We now well stir up and agitate the liquor in the boiler, in order that the animal charcoal, and other substances, may have the greater effect in blanching the liquor. And after the coagulated albumen has completely risen in the form of scum by the application of heat, in the usual way, we either skim it off, as in the common process, or we pour the whole of the liquid sugar and scum into and upon

the usual or any other known filter, when this clarified liquor is completely separated from the albuminous matter, as well as from the animal charcoal, or other substances employed; taking care to return back into the filter the first runnings of the said liquor, if not quite separated from the above substance used. And, further, we proceed in the usual manner to evaporate, granulate, and refine, the said liquid sugar so clarified. And, further, we boil over and filter our scum in the usual manner. We further declare, that the sugar so clarified and refined is preferable to sugar refined in the heretofore common mode, inasmuch as it is purer and whiter. And we further declare, that the syrups obtained by this process have not that tendency to ferment which the syrups have which are produced in the heretofore usual method.

A patent, dated June 22d, 1815, was granted to John Taylor of Stratford, in the county of Essex, manufacturing chemist, for a method or methods of purifying and refining sugar. The patentee, in his specification, declares that his invention is applicable to the purification and improvement of raw sugars, if employed in the original manufacture in the West Indies; or that the said raw sugars, as now commonly imported into this country, may thereby be improved in quality here, so as to render the subsequent operations of refining less complex and expensive than when raw sugar not so purified is employed. The patentee states the nature of his invention to be as follows: "I have found that the melasses and other soluble impurities contained in raw sugar may be separated therefrom by mechanical means, without the use of heat; and that by abstracting these from the raw sugars, the injury caused by their mixture with the refined sugar in crystallizing is avoided. For purifying raw sugar according to my invention, it must first be brought to a moist state; and if the process be employed in the original manufacture in the West Indies, the degree of moisture at which the sugar will be upon draining a short time after it is taken from the coolers in which it is crystallized, will be sufficient. But if my said invention be practised in this country on sugars as dry as they are usually imported, they will require to be mixed with a certain proportion of cold water, or lime-water. This proportion may be varied according to the opinion of the operator and the quality of the sugar, and will readily be determined by trial, as no exact rule can be laid down for each case:—in general, the proportion of water may be from one-eighth to one-tenth of the weight of the sugar. The sugar and water are to be well mixed in any proper vessel, and the whole is then to be subjected to pressure, carried to such a degree as to express all the fluid part therefrom, which will be found to contain the melasses and soluble impurities, and a certain quantity of sugar in solution; and the sugar, if the pressure be sufficient, will be rendered dry, and much improved in colour and appearance.

"I further declare, that though my invention may be carried into effect in a variety of ways, by using presses of various construction, and by exposing the sugar to pressure in a variety of modes, yet that the following operation is the one which by preference I adopt. After the sugar has been mixed with water, or otherwise moistened, I inclose it in strong linen or woollen cloths, each of which is cut about thirty inches square, and being laid over a wooden box twelve inches square and two inches deep, some of the moistened sugar may be pressed in, and the cloth folded round it so as to form a square cake. A press is to be constructed with a platform, capable of containing at least four piles of these cakes, which may be arranged so as to stand at a certain height, and may then receive a degree of pressure, which will cause the fluid part to flow out, and which is to be received in a copper pan, fixed upon the platform of the press, and furnished with a spout, to convey the expressed syrup into a receiving vessel. While these cakes are pressing, another set is to be got ready, and the first having been hardened with pressure, may be adjusted so as to keep the piles upright, and the fresh cakes set upon them, and so exposed to pressure. In this way a considerable quantity of sugar may be got into a press, and, after having been moderately hardened, the whole should be taken down, and again set up, and exposed to a higher degree of pressure, which will render the whole dry, and of uniform good colour and appearance.

"I further declare, that any machine or apparatus is capable of applying pressure to sugar, either vertically or horizontally; and whether the sugar be inclosed in cloths, as I have described, or in bags, or in cases, frames of wood, metal, or other materials, may be used for the purpose of my invention; but that I prefer the mode I have herein pointed out; and that I have found the hydrostatic presses, and commonly known by the name of Bramah's presses, most convenient for the purpose.

"And I further declare, that the sugar prepared and purified in the way I have described is much improved, and may be refined into lump-sugar by any of the processes for that purpose, and with less expence and trouble, and in less time, than is required for raw sugar not so purified. And further, that if my said invention be applied to the original manufacture of sugar in the West Indies, the sugar so prepared will be fit for immediate shipment, as all the time required for draining and drying will be saved, and all danger of fermentation prevented.

"And I do further declare, that the sugar contained in the expressed syrups may be obtained therefrom by the usual processes of evaporation, and from its not being injured by the usual application of heat, is capable of being made into an inferior sort of refined sugar."

SUGAR, *Barley*, *saccharum hordeatum*, is a sugar boiled till it be brittle, and then cast on a stone anointed with oil of sweet almonds, and formed into twisted sticks, about the length of the hand, and the thickness of a finger.

It should be boiled up with a decoction of barley, whence it takes its name; but, in lieu of it, they now generally use common water, to make the sugar the finer. To give it the brighter amber colour, they sometimes cast saffron into it. It is found very good for the cure of colds and rheums.

SUGAR-*Candy*, *Saccharum Candum*, or *Crystallinum*, is sugar depurated and crystallized, and differs from common sugar in being much harder and transparent. See CANDY.

The sugar to be used in this process is first dissolved in a weak lime-water, then clarified, scummed, strained through a cloth, and boiled, and put in forms or moulds, that are traversed with little rods, to retain the sugar as it crystallizes. These forms are suspended in a hot stove, with a pot underneath, to receive the syrup that drops out at the hole in the bottom, which is half-stopped, that the filtration may be the gentler. When the forms are full, the stove is shut up, and the fire made very vehement.

Upon this, the sugar fastens to the sticks that cross the forms, and there hangs in little splinters of crystal. When the sugar is quite dry, the forms are broken, and the sugar is taken out candied. Red sugar-candy they make, by casting into the vessel, where the sugar is boiling, a little juice of the Indian fig; and if it is desired to have it perfumed, they cast a drop of some essence in, when the sugar is putting into the forms.

This method of making ſugar-candy is that of F. Labat, practiſed in the Caribbees.

The method among our manufacturers is as follows. A ſtove is ſet apart for this purpoſe, the entrance into which is in the ground floor, and as near as poſſible to the pans; and the top is uſually from ten to fourteen feet above the ground, and covered like the top or crown of an oven. Beams are faſtened into the walls, at the diſtance of about twenty-ſix inches from each other, and ſufficient to bear a very large weight: upon which ſtrong planks are laid when they are wanted, and upon the planks the candy-pots are ſet: when the ſtove of candy is finiſhed, the planks are removed. The pots are uſually made of thin copper, without feet, and with an iron rim round the top, to ſtrengthen them: the bottoms are hammered into the moſt perfect flatneſs, that they may ſtand firm and ſteady: they are perforated in rows on two ſides with holes about one-tenth of an inch in diameter. According to the old method of piercing, the holes were very cloſe laterally, and the candy of each ſtring united with that of the next, and the whole formed a ſtrong cake: but according to the improved method, the holes are kept at a proper diſtance apart, *i. e.* at the diſtance of one inch and a half in the upper rows, and widening downwards to two inches; and the candy is formed in diſtinct bars, more convenient for package and ſale, and much more beautiful than the former.

When a ſtove of candy is intended to be made, the cockell ſhould be moderately heated, at leaſt twenty-four hours before the operation begins; and the candy-pots are ſtrung, *i. e.* a coarſe white thread is drawn by a needle through the firſt hole of the bottom row, and the end being faſtened there, the thread is led acroſs the inſide of the pot to the oppoſite hole, and continued from ſide to ſide, till that row is finiſhed: the next row above it is then ſtrung in the ſame manner, &c. till every row is finiſhed. The pots, being all ſtrung (*viz.* about forty to each pan of ſugar), muſt be paſted, *i. e.* the holes muſt be ſtopped either by paſting papers over them on the outſide, or by bruſhing any glutinous matter over the outſide. When the ſtoves and pots are ready, the workman places five pots upon the pavement, beginning either at the right or the left-hand corner of the ſtove oppoſite to the cockell.

The management of the pans is nearly the ſame as has been deſcribed under *Refining of* SUGAR, with ſome ſmall difference. The ſugar intended for candy ſhould be cleared with leſs water than other goods: the lime-water for brown candy ſhould be of the greateſt ſtrength; and the workman endeavours to extract the ſcum as ſoon as poſſible, becauſe it is imagined that the ſtrength of the ſugar may be impaired if it be ſuffered to lie too long diſſolved. No ſcum is ever incorporated with the ſugar intended for candy; indeed four or ſix gathering-pots to a pan are ſometimes taken; but it is apprehended, that it would be better to omit even this. The ſugar melted for candy ſhould be the ſtrongeſt that can be obtained.

When theſe precautions have been obſerved, let us imagine the ſugar cleared off and ſkipped into the ciſtern. The panman pumps back about the uſual quantity: the boiler carries the evaporation to the point he judges proper; and it is immediately ſkipped off into baſons, which are carried directly to the ſtove; and the pots are then filled in the following manner. The fill-houſe man receives the firſt baſon, and pours its contents into N° 1, proceeds to N° 2, and ſo on, till he has reached N° 5; and then proceeds to fill N° 5, 4, 3, 2, and 1. When this ſet is filled, the fill-houſe man goes on till he has covered the whole pavement: he then lays two planks upon the loweſt beams, and places a ſeries of pots upon the farther one, ſtanding upon the other to fill them: he then lays down another ſtrong plank, and covers that on which he ſtood, and ſo proceeds to build up row after row, till the whole is finiſhed. In the whole progreſs of this buſineſs he moves ſlowly and cautiouſly, and cauſes all the doors to be ſhut, ſo that no currents of air may approach him; as ſtillneſs is of the greateſt conſequence, and the leaſt concuſſion of the air is ſufficient to diſturb and break the cryſtallization. When the pots are filled, the ſtove-door is faſtened up, and covered with a blanket, or ſtopped with wet clay. The cockell is ſtoked to ſuch a degree, that the candy may ſtand in a blood-heat; at the end of ſix or ſeven days, the cryſtallization of brown candy will be complete. The pots are then removed from the planks and the floor, and the operation commences, which is called *ſtirring*, or *breaking-up* a ſtove of candy. Each pot is brought to the ſide of a cooler, upon which, over a frame, a clean baſket is laid, into which all the ſugar that has not cryſtallized is poured off, and along with it the *cruſt*, which is a coat of candy, that had formed itſelf upon the ſurface: the ſyrup or uncryſtallized ſugar runs through the baſket into the cooler, but the cruſt remains in the baſket, in which it is waſhed and dried, and afterwards packed for ſale with the candy. As ſoon as the ſyrup is poured off, the pot is brought to the ſide of the pan, and ladles of clean water, blood-warm, are poured in till it be nearly filled; the pot is then ſmartly ſhook round, and the water is returned into the pan. The candy being thus worked, the boiler examines it. If it be ſtrong and good, it preſents a beautiful appearance; the ſides of the pot are every where covered with a coat about half an inch thick, the front of which is cut in ſtarry forms, reflecting the light in various directions; and upon every line the cryſtals faſten in the moſt varied and capricious forms. If the pots were pierced, as they formerly were, ſo that the ſtrings might lie but an inch aſunder, the candy of each line would then run into the next, their ſides become united, and the whole form a ſtrong cake, not to be ſeparated without force: but the modern improved pots are ſo pierced, that the cryſtals are ſuſpended upon every thread in diſtinct bars, without either lateral or perpendicular coheſion.

The waſhing above deſcribed is neceſſary to cleanſe from the face of the cryſtals every particle of ſyrupy matter, which would otherwiſe occaſion a clammineſs in the candy, and obſcure its luſtre. After waſhing, each pot is turned down into a cooler or other receiver, to drain, and when they are waſhed and drained, they are again put into the ſtove to be dried; for this purpoſe they are placed in the ſtove aſlant, reſting againſt the wall, or againſt each other, with the mouth downwards; and under each pot is placed a ſmall earthen pan, called a *candy-baſon*, to receive the remaining moiſture which will drip from them: the ſtove is again faſtened up, and the cockell ſtoked, ſo as to produce a fierce fire, which muſt be well kept up for three days: at the end of which time the candy will be dry enough to quit the pot; they are therefore taken out of the ſtove, and turned down upon the floor, previouſly covered with clean paper; and with a little ſhaking, or a gentle blow, the whole maſs of candy quits the pot, retaining the form of it complete: and then the candy is returned to the ſtove for the third and laſt time, where in three or four days, with a good fire, it will become perfectly dry, and fit for ſale. It is generally packed in boxes of about fifty-ſix pounds each: at the bottom of the box is a layer of the bottoms of the pots, which have the leaſt beauty or fineneſs; then a courſe of bars of candy, upon that a ſtratum of cruſt, and ſo on to the top of the box, finiſhing with bars of the handſomeſt

candy, neatly laid with the face upwards. At the bottom of the candy there are often found maffes of fugar which hath not yet cryftallized, but is become concreted in fmall round grains, of a lighter colour than the candy; this is called *foot*, and is either fold at a lower rate, under the name of *candy-foot*, or melted with other fugar, for the making of lumps and loaves. The fyrup of candy is fit to be taken copioufly with raw fugar in lump-boiling. The wafhings and the drips from the bafon are applicable to the fame ufes.

White-candy is made like the former, but from fine lump or loaf fugar, cleared as for double loaves. It is boiled to lower proof; ftands in a milder warmth; forms in three days inftead of feven; and the value depending upon the whitenefs, it muft be managed with the utmoft delicacy in every ftage of the procefs.

The *brown* fort cryftallizes as regularly as the white, but becomes clammy and deliquefcent in a damp air, whereas the white candy remains always dry. On account of its fuperior hardnefs, it is lefs eafily foluble than the loaf-fugar, and would be excellently calculated for preferving all vegetable food, if the price was lower. The fole difference between the white candy and the fineft loaf appears to be in the form, which in the candy is the natural faline form of fugar, but in the loaf is granular, owing to the agitation given to it for this exprefs purpofe whilft cooling. The moft common form of the regular cryftals of fugar-candy is an oblique four-fided prifm, terminated by dihedral fummits.

White fugar-candy, and alfo fugar, are ufed as ingredients to render water a vehicle for colours in miniature-painting. The intention of ufing them is to prevent the colours from cracking when mixed with gum-arabic, and alfo to make the gum-water work more kindly with the pencil. See Starch.

Sugar-*Houfe*, is a brick or ftone building, conftructed for a fugar-refining manufactory. A houfe intended to contain one or two pans fhould be fquare, or nearly fquare: but a houfe of larger dimenfions ought to be of an oblong form; as it may be conveniently heated, by placing the chimney of the ftove and of the pans at oppofite angles. A houfe to contain one pan fhould confift of fix floors befides the ground-floor; the dimenfion about twenty-feven feet fquare: a two-pan houfe about thirty-fix feet by forty feet: a houfe of four pans, about forty feet by fixty or fixty-five feet. The ftove is a brick building from eight to fourteen feet fquare, ufually placed in one corner of the building. The height of the feveral ftories fhould be as follows; the fill-houfe, or ground-floor, nine feet below the girders; the next floor above it, called the *warehoufe*, of the fame height; and every other floor upwards, fix feet at moft between the girders and the floor. In every floor muft be left an aperture, through which a rope is fufpended upon a brafs pulley on the uppermoft floor for drawing up the fugars: and provided due attention be given to the ftrength of the building, and to the exclufion of damps and a cold air, a fugar-houfe cannot be rendered too light. The utenfils neceffary to a fugar-houfe are of copper, lead, iron, carpentry, back-maker's work, wicker-work, pottery, &c. The copper utenfils are the pans, coolers, cifterns, fyrup-pipes, bafons, ladles, fkimmers, and, in fome cafes, candy-pots, &c.

The pans are ufually made of a conical form, from five to fix feet diameter at the top, decreafing to a diameter of about two feet fix inches, or three feet. The coolers are veffels of thin copper, of fix feet in diameter, and about twenty inches high: the number of pans and coolers is ufually the fame. The clarifying ciftern is a large receiver, either of copper or lead, placed as near as poffible to the fides of the pans, and capable of containing at leaft one-third more than the contents of all the pans collectively. The fyrup-pipes are tubes of four inches diameter, made of thin copper, or tin-plates, and fufpended perpendicularly over the clarifying ciftern, from the upper floor through the whole building. The bafons are veffels containing from four to fix gallons each, in which the boiled fugar is carried from the pans to the coolers, and from the coolers to the moulds. The ladles are of feveral fizes. Skimmers are of fourteen inches diameter, pierced with holes like a cullender; and likewife a fmall one of the fame kind. Cullenders are of eighteen inches diameter, and fourteen inches deep, through which the clay is to be ftrained: and there is alfo another, which is fmaller, for the purpofe of ftraining fpice.

The leaden utenfils and plumbers' ware, are fuch as follow: the bench is a ledge about one foot broad, running before the pans, and rifing in front, by which it is capable of receiving the fugar which is fpilled before the pans. The fcum-ciftern is a wooden receiver, ufually lined with lead, and nearly as large as the clarifying ciftern.

The water-pipes are a pewter or hard metal pipe from the lime-ciftern to the pans, and leaden pipes for the conveyance of common water or liquor to the pans, and to the lime-cifterns. The pumps are a copper pump fixed in the clarifying ciftern, and a fpare pump of the fame kind.

The iron-founder fupplies bars of a triangular form, to be laid under the pans, and the cockell, which is an iron trunk, ufed to dry the goods in the ftove; and alfo iron doors, ftove-doors, and pan-doors, &c.

The carpenter raifes the fteam-vent over the pans, which is a hood of thin board, fo formed as to conduct the fteams to the two brick funnels, which are led up on either fide of the pan-chimney to the top. He alfo furnifhes the racks of the ftove, a trough to convey the fugar from the pans to the ciftern, and another to return it from the ciftern to the pans, fyrup-ftools, blocks, cooler oars, &c.

The back-makers fupply two or more tubs or backs for lime-water, which are round, oval, or fquare, and whofe capacity varies from thirty to two hundred barrels. The liquor-back, is any veffel large enough to hold a confiderable quantity of common water. The mould-ciftern is a large oblong veffel, in which the moulds are foaked before they are ufed: it is ufually about four feet fix inches deep, and fhould be capable of containing at once as many moulds as are ufed in one day's refining.

The clay-cifterns are fupplied either by the back-maker or carpenter, and alfo the clay-ftar, which is made of oak or elm, its club end being ftuck full of iron points: its ufe is to macerate and fine the clay.

The wicker-work confifts of refining-bafkets, fcum-bafkets, pulling-up-bafkets, coal and clay-bafkets, &c.

The fugar-mill is one of the moft fimple machines of the kind: the runner is fometimes made of caft-iron and fometimes of ftone: the former is preferable, becaufe a larger diameter and a broader furface may be had with the fame weight. The runner and the centre poft fhould have a brafs collet within them, for the iron fpindle to turn upon. The mill fhould ftand on a folid foundation; either on the earth, or on the centre of a brick or ftone arch. The veffels of pottery are of various fizes, and of two different forms and denominations, *viz.* pots and moulds.

The conftruction of the pan-chimney requires peculiar attention; it fhould be placed on iron bafes, and the horizontal bars on which it refts muft be wrought in the walls of the building, and clenched down on the outfide. But the fetting of the pans is the moft difficult work; for it is neceffary that they fhould be fo fixed, as that the ftones,

which burn away under them three or four times in a year, ſhould be taken out and replaced, without pulling down the whole work.

After all, a principal conſideration in the conſtruction of a ſugar-houſe, is the obtaining a ſufficient degree of heat. Various degrees of heat are required for different ſorts of goods, and occaſionally for the ſame ſort: accordingly each floor may be made more or leſs warm, as the caſe requires. The heat is introduced through the pan-chimney, the ſtove-chimney, and ſometimes through iron or brick flues raiſed on purpoſe. It is communicated from the chimnies by ſhutting the regiſter-plates, after the fires are extinguiſhed, or when they are nearly out, and the remaining aſhes are perfectly clear. After ſhutting the regiſter-plates, the ſmall iron doors (one of which is fixed in the chimnies both of the cockell and the pans upon every floor) are opened, to convey heat where it is wanted.

Labourers in ſugar-houſes are very ſubject to dyſenteries: the *vitrum antimonii ceratum* is an effectual remedy in theſe caſes.

SUGAR-*Mill*, a machine uſed in the Weſt Indies to preſs out the juice from the ſugar-cane, as briefly deſcribed under our article SUGAR, *ſupra*. The ſugar-mill is a very ſimple machine, conſiſting only of three vertical rollers mounted in a frame. The power is applied to the centre one to turn it round, and all the three are made to turn together by means of cog-wheels. The canes are introduced between theſe rollers, which as they turn round draw in the canes and give them a very violent preſſure, which is ſufficient to extract the juice and leave the canes dry.

Sugar-mills are worked by cattle, wind, or ſtreams of water; and ſince the improved ſteam-engines of Mr. Watt have become general, many ſteam ſugar-mills have been ſent out to the Weſt India plantations. In ſituations where a fall of water cannot be obtained, theſe are preferable to cattle-mills or wind-mills; for if cattle are uſed, an extra ſtock ſhould be kept on purpoſe, becauſe the regular cattle of the plantation are fully employed at the ſeaſon of cutting the canes. The operations of the mill ſhould be carried on conſtantly in a regular manner, until the whole crop is finiſhed, or there will be danger of the juice fermenting in the canes, if the machinery is not ſufficiently powerful to extract the juice from the canes as faſt as they are brought in from the field in bundles. For this reaſon wind-mills are very objectionable, as no dependence can be placed upon them for fulfilling their allotted taſk in the required ſeaſon. In many wind-mills levers are provided, to which mules or oxen can be harneſſed, to work the mill when the wind fails, the machinery of the ſails being then detached. But this expedient takes off the cattle from their regular field employment. A water-mill, or ſteam-engine, is free from theſe objections; and if it is ſufficiently powerful, the whole produce of a plantation can be preſſed, and the juice obtained ready for the boiling-houſe, in ſo ſhort a time that the juice will be quite freſh. There are ſome water-mills in Jamaica, ſufficiently powerful to grind as many canes in a week as will make thirty hogſheads of ſugar.

Plate Sugar-Mill contains two views of a ſugar-mill to be worked by ſteam. K repreſents the axis of the crank of the ſteam-engine, and L the fly-wheel; I is a pinion, fixed upon the end of the axis K, and turning the large cog-wheel H, which is faſtened upon the extremity of the horizontal axis G. The beams M, which ſupport the pivots of the two latter wheels, are built into a wall, which may be conſidered as the wall of the houſe in which the ſteam-engine is placed. At the oppoſite end of the horizontal ſhaft, G, is fixed the bevilled cog-wheel F, which gives motion to the horizontal bevilled wheel E, fixed upon the top of the axis, D, of the middle roller B. The two other rollers, A and C, are placed on each ſide of it, and all three are made to turn round together by a cog-wheel, S S S, at the upper end of each. The rollers are mounted in an iron frame, conſiſting of two horizontal frames, P P, Q Q, ſuſtained by uprights O, O, and the openings of the frames P, Q, contain the braſs bearings for the pivots of the three rollers, which braſſes are adjuſtable by means of croſs keys, and wedges driven through openings in the frames, ſo as to force the rollers towards each other, and retain them at a regular and invariable diſtance. The ſurfaces of the rollers are fluted, as is ſhewn in the figure, with grooves of a ſmall depth. Theſe make the rollers take a firmer hold of the canes to draw them in, and alſo facilitate the running down of the juice from the canes into a pan or ciſtern, which is formed round them at the lower part Q Q, by a plate of iron upon the frame Q, turned up all round at the ſides; and at one end there is a ſpout, Q, to carry off the juice into a pipe, which leads to the boiling-houſe. This receptacle for the juice forms a ſmall circular channel or gutter round the lower edge of each roller, to receive the juice which runs down the ſurface of the rollers; but a ſmall raiſed rim is carried round the centre part or pivot of each roller, the edge of which is higher than the ſurface of the liquor in the pan, to prevent the juice flowing down into the bearings of the lower pivots. The weight of each roller, which is conſiderable, is ſupported in a braſs ſtep or bearing beneath the frame Q Q, as is ſhewn by the dotted lines in *fig.* 1; and in ſome caſes friction-rollers are applied beneath. The rollers are made of caſt-iron, and hollow within; the external ſurfaces are truly turned.

The operation of the ſugar-mill is extremely ſimple: the canes are made to paſs twice under the preſſure, firſt between the rollers B, C, and then between B and A. For this purpoſe, the negro who attends and feeds the machine, takes the canes in a handful, and applying their ends between the rollers B and C, the motion will draw the canes in between them, and they thus receive a firſt preſſure. Another perſon, who ſtands behind the mill, and is called the returner, bends the ends of the canes as they come through, and holds them in contact with the ſurface of the centre roller B, ſo that it will carry them round by its motion, and introduce them again between the rollers A, B, where they will come out again in front, preſſed dry from their juices. The ſecond pair of rollers, A, B, are adjuſted by the wedges of their bearings, ſo as to be rather nearer together than the firſt pair, becauſe the canes are flattened and cruſhed by the firſt preſſure between the rollers B, C, and require a ſtill greater degree of preſſure the ſecond time. The ſpace between the rollers is very ſmall in either caſe, for the canes are of a very ſoft ſubſtance, and they are ſqueezed exceſſively hard in paſſing between them. In the moſt complete mills they employ what is called a dumb returner, inſtead of having a perſon behind the mill to return the canes. This is a circular piece of frame-work, or kind of ſcreen, which is fixed faſt to the frames P and Q, and is made to encompaſs the middle roller at the back. It receives the canes as they come through the firſt time, and holds them in contact with the middle roller, till the ends return between the other pair of rollers. It effects this much more completely than the moſt attentive returner can do. The canes which have paſſed through the mill are ſqueezed completely dry, and are ſometimes even reduced to powder. This refuſe is called cane-traſh, and is uſed as fuel in the boiling-houſe.

Sugar-mills were formerly made of wood in the framing, and the rollers were made of hard wood; afterwards they were covered with an iron casing. The best mills are now made wholly of iron, which is a better material, because it will not suffer the rollers to yield, and the canes which are presented cannot escape the full force of the pressure to which it is intended to subject them. When the sugar-mill is turned by cattle, the axis, D, of the middle roller has a long lever fixed across it, in place of the wheel E: the arms of the lever extend on each side at least eighteen feet from the centre, for the cattle to draw from; and to render the arms firm, the axis L is carried up to a considerable height above E, and oblique braces of wood are extended from the extremities of each of the arms, by which the horses or mules draw, to the top of the vertical axis, thus forming a triangle. Two mules are harnessed to each arm for the common small mills; but for a mill such as is represented in the drawing, four arms must be provided, to admit of six or eight mules to turn it.

Some sugar-mills have been made within these few years of an improved structure: the rollers are placed horizontally, and the centres of the three are arranged in a triangle, two rollers being below and one above them, so that the upper roller, to which the power is applied, touches the other two: in fact it rests upon them, and the returner is rendered unnecessary, because the two lower rollers are so near together, that the canes pass from one to the other. This is not a new invention, as we find a drawing of it in Mr. Smeaton's MS. papers entitled "sugar-mill, designed for Mr. Grey in 1754, and sent by him to Jamaica, but not then executed." This mill, which is on a large scale, and has two sets of rollers, is worked by an overshot water-wheel, the axis of which forms the upper of the three rollers at each end, and is for that purpose cased with a cylinder of iron: the other two rollers at each end of the wheel are placed beneath the axis, so that it will rest upon them. The upper roller, therefore, answers to the middle roller of the common sugar-mill, and the two lower ones to the outside rollers; but the centres being arranged in a triangle, instead of a straight line, the two outside rollers are brought as near together as they can be not to touch, which must not be, because their surfaces move in opposite directions. The two lower rollers are contained in a small cistern, which is to receive the juice; and if the level of the water-wheel renders this cistern too low for the juice to run off to the boiling-house, a small pump is applied to lift it into a proper trough. This pump is worked by a lever and a pin, projecting from the shaft of the water-wheel. The two lower rollers are turned round by means of a cog-wheel upon the end of each, working in cog-wheels upon the axis of the water-wheel and upper roller; but it is necessary to have two separate cog-wheels upon this axis, because as the two lower rollers are placed so near together, the cogs of their wheels would touch; and as this cannot be, because the adjacent surfaces of the two lower rollers must move in contrary directions, the cog-wheels upon the two lower rollers are therefore placed in different planes, so that they will fall side by side, and will not meet each other. The teeth of the cog-wheel upon the upper roller or axis of the water-wheel is made of double breadth, or has two separate rings of cogs, one giving motion to each of the rollers. By this means the three rollers are all turned round in the same direction, as in the common vertical mill. This occasions the two adjacent sides of the two lower rollers to move in contrary directions.

The advantages of placing the rollers horizontal are considerable. The weight of the water-wheel, as well as its power of rotation, tend to keep down the upper roller upon its work. The feeding of the mill is rendered much more regular and easy, and the canes are returned through a second pressure, without the aid of the returner.

For the convenience of feeding the mill, a board or bench is placed in a sloping direction, leading to the space between the first of the lower rollers and the upper roller: upon this bench the canes are spread in a regular and even layer, which is pushed forwards, and enters between the rollers, in the same manner as a threshing-mill is supplied. The canes as they pass through are pressed against the surface of the back lower roller, because the space between the two is not sufficient for the canes to fall through; and the motion of the back roller raises up the canes, and introduces them between the back roller and the upper roller. This second pressure deprives the canes of all their juices, and they are received on an inclined board, which slopes from the rollers sufficiently to carry down the cane-trash into a heap, from which it can occasionally be carried away. A mill of this kind will do much more work than a vertical mill, for the negro must lose time in feeding the canes between the vertical rolls, because he can only present as many as he can hold between his hands; but with a horizontal feeding board he spreads out a sufficient quantity of canes, and by pushing them forwards, presents them to the mill as fast as it will take them in, and that at the same time without choaking, because he can arrange them in a layer. There is no advantage in placing the rollers vertically, which was originally done only with a view of making the most convenient application of the power of the cattle. When a water-wheel is used, or a steam-engine, the horizontal rolls are the most convenient as well as the most effective. When a water-wheel is applied to turn the common sugar-mill, the wheel E, at the top of the axis of the middle roller, is made twice or three times as large as represented in the figure, and its teeth downwards; then a wheel, similar to the wheel F, gives it motion: this latter wheel is fixed upon the end of the axis of the water-wheel, but it is then placed beneath the wheel E, instead of above it.

Sugar, in *Agriculture*, is a material that is found to be present in many substances which are employed as the food of domestic animals, and upon which their power of nourishing and rendering them fat, in a great measure, depends. It is ascertained to exist, in a pretty large proportion, in a great number of plants and substances that are used in this way; and its feeding or fattening properties in such cases have lately been put to the test and more fully proved, in consequence of the markets of this country having been so much overstocked with this substance in its prepared state, from our possessions in the West Indies. Various hints, proposals, and attempts, for bringing it into use in this intention, have been made; and different limited trials have fully decided that it is capable of being employed for this purpose with success; but hitherto the want of proper regulations in regard to the duties that have been laid upon it in this country, have put a bar to any considerable trials or undertakings in this way. Most sorts of the above description of animals are fond of this substance, as well as the other matters which contain it; and it is found to support and keep them in condition in an equal manner to most kinds of grain, or other matter of that kind; but from the smallness of the quantity employed, some sort of distending material is constantly necessary, such as hay, cut straw, chaff, or some other similar bulky substance, in order to fill and distend the stomach in a proper manner. See Saccharine *Matter*.

It is observed on the same authority, that besides the

cryſtallized and ſolid ſugars, there appears to be a ſugar which cannot be ſeparated from water, and which exiſts only in a fluid form; and that it is this which conſtitutes a principal part of melaſſes or treacle, which has alſo been employed with ſucceſs in fattening animals of the cattle kinds, in mixture with ſome ſort of diſtending ſubſtances. See STALL-*Feeding*, and TREACLE.

SUGAR, in *Chemiſtry* and *Medicine*, denotes a cryſtallizable eſſential ſalt, of a ſweet agreeable taſte, contained more or leſs plentifully in many kinds of vegetables, as well as in the ſugar-cane, which furniſhes the greateſt quantity of it.

Sugar, according to the experimental trials of ſome, contains carbon, oxygen, and hydrogen, nearly in the proportions of three of the firſt, four of the ſecond, and eight of the laſt. And the eſtimates of others give the ſame elementary parts, as in ſubſtances of the gum kind; as eleven of carbon, ten of oxygen, and twenty of hydrogen.

M. Marggraf has obtained ſugar from the roots of ſeveral plants, as from carrots, parſnips, white and red beets. Among all the vegetables indigenous to the middle and north of Europe, which are ſenſibly ſaccharine, the beet-root is found to exceed them all in the quantity of ſugar which it contains: this was aſcertained by M. Marggraf, in his experiments for diſcovering ſome native ſugar that might ſerve as a ſubſtitute for foreign ſugar. (Mem. de l'Acad. de Berlin, for 1747.) See BETA. Two methods were purſued by this accurate chemiſt. One was to dry a given portion of the vegetable, to boil it in rectified alcohol, and then keep the alcoholic ſolution at reſt for a time, by which the ſugar will ſeparate in cryſtalline grains. This mode, however, is much too expenſive to be purſued in manufacture, but it ſerves as an uſeful indication of the *comparative* proportions of ſugar in different vegetables, though the *actual* quantity obtainable by the uſual mode of manufacture appears to fall far ſhort of what is yielded by treatment with alcohol.

The other method was to imitate in the ſmall way the proceſs performed on the ſugar-cane juice, which alſo was attended with a certain degree of ſucceſs. The experiments of this celebrated chemiſt are the following: three roots were ſelected, the white beet, the red beet, and the ſkirret, all of which gave evident indications of abounding in ſugar, for when cut in ſlices, and dried, their taſte is very ſweet, and the microſcope ſhews a number of cryſtalline grains of ſugar diſperſed through their ſubſtance.

Some ſlices of white beet thoroughly dried, but not burnt, were powdered coarſely, and 8 oz. of this powder, again dried, were put into a bottle with 16 oz. of highly rectified alcohol, and being looſely ſtopped, the liquor was ſlowly brought to boil on a ſand-bath, with frequent ſhaking. The veſſel was then removed, the ſolution filtered, and the powder preſſed ſtrongly, to ſqueeze out all the liquor. This clear ſolution was then put into a bottle which was corked, and ſet by in a cool place. A cryſtallized ſalt depoſited gradually in the courſe of ſome weeks, which was hard and tolerably pure ſugar. This was rediſſolved and again cryſtallized in the ſame way, by which a very pure ſugar was obtained. In this way, 8 oz. of the white beet-root gave half an ounce, or $\frac{1}{16}$ of ſugar; 8 oz. of ſkirret-root, equally dried, gave 3 drachms, or about $\frac{1}{21}$ of ſugar; and the ſame quantity of the red beet gave only $2\frac{1}{2}$ drachms, or about $\frac{1}{26}$ of ſugar. The ſolution, however, ſtill contained a quantity of ſugar mixed with the reſinous part of the root, and if it is evaporated to dryneſs, a ſweetiſh uncryſtallized extract remains.

The ſkirret-root was then treated in the following manner without alcohol, with a view of extracting the ſugar. A quantity of it was chopped ſmall, bruiſed in a mortar, and the juice expreſſed through a cloth bag, and the pulp was again moiſtened with water, and expreſſed, to get out all the ſaccharine liquor. The whole liquor was then kept at reſt for 48 hours, in a cool cellar, by which moſt of the feculence ſubſided, and the clear liquor was carefully drawn off. The author lays much ſtreſs on this part of the proceſs, which, if it is not done properly, conſiderably hinders the ſubſequent production of the ſugar. The clear liquor was then heated in a copper pan, clarified with white of egg, and boiled down to the conſiſtence of thick ſyrup, and kept in this ſtate for about ſix months in a warm place, by which it concreted into a ſemi-fluid cryſtalline maſs, compoſed of impure cryſtals of ſugar and a good deal of ſyrup. The whole maſs was then a little warmed, to give the ſyrup a little more fluidity, and poured into a funnel-ſhaped veſſel of tinned iron, with holes at the ſides and bottom, and ſet by in a warm place; by which, after a conſiderable time, the impure uncongealable ſyrup ſlowly filtered to the bottom, leaving the purer ſaccharine part in the form of a brown granular maſs. The latter was then re-diſſolved in water, again clarified with white of egg, ſtrained, boiled with a little lime, again ſtrained, and then evaporated to a thick conſiſtence, and ſtirred till cold. A ſugary viſcid maſs ſtill purer than the laſt was thus obtained, which, on being kept for a week in a funnel-ſhaped pot, with a ſingle hole at bottom, plugged up, congealed into a grained ſugar equal to good muſcovado, from which a ſyrup ſeparated and dropped through when the plug was withdrawn.

Such is the proceſs of this chemiſt to obtain a ſugar from the ſkirret-root, and he proceeded in the ſame manner with the white and red beet-root, and with the ſame ſucceſs. He further obſerves, that he raſped the beet-roots, being harder than the ſkirret; that the mucilaginous depoſit from the beets was browner and leſs copious than from the ſkirret; the ſugar from the white beet was the moſt abundant and the pureſt, and that from the red beet was the leaſt ſo. The mucilage or ſediment from the ſkirret, waſhed with cold water and purified, yielded a very good white farina.

All theſe roots are very watery. The white beet loſes by gentle, but entire, deſiccation, full three-quarters of its weight, and the red beet ſeven-eighths.

For an account of the experiments of Achard, and other chemiſts, ſee BETA.

It is alſo preſumed, that much ſugar may be obtained from other vegetables, as from green peas, cabbage, green farinaceous grains, as barley, (ſee MALT,) ripe fruit of grape, date, and fig, and the root of parſnip, &c. and from ſeveral trees, as the ſycamore and birch trees. Green maize (ſee MAIZE) contains a liquor from which the American ſavages are ſaid to extract ſugar. It may alſo be extracted from the *aſclepias caule erecto ſimplici annuo*, and from any flowers collected while the morning dew is upon them. But the vegetable which yields the largeſt quantity of ſugar, next to the ſugar-cane, is the ſugar-maple. (See MAPLE.) The methods employed for extracting ſugar from this tree in Canada are related by M. Gautier, in the Mem. des Scav. Eſtrang. tom. ii. and by M. Kalm, in the Swediſh Mem. for 1757. (See MAPLE *Sugar*.) The ſeaſon for tapping the tree is from February to April, for about ſix weeks, during which time a tree of moderate ſize will yield from 20 to 30 gallons of ſap, from which may be made about five or ſix pounds of pretty good ſugar. The tree does not ſeem to ſuſtain any injury from this operation, for the juice is more ſaccharine from the trees that have

been already tapped, than from thofe that are frefh. This juice, which is clear, and of a pleafant tafte, is made into fugar by the farmers in the country, with a fimple apparatus. It is ufually clarified with lime and white of egg (or milk) boiled down, grained, and clayed, like the cane-juice. Sometimes the quantity of liquid is reduced by freezing at the proper feafon, which is preferred to evaporation. This fubftance might, it is fuppofed, be made into loaf-fugar, as well as the mufcovado; and it is commonly ufed in a half-purified ftate, like the common moift fugar. The juice will alfo furnifh a pleafant wine by fermentation, and a good vinegar.

By difcovering a menftruum that would diffolve the fugar, and not the flimy fubftance, the faccharine and mucilaginous parts of plants might be feparated from one another with advantage. Sugar is fcarcely, if at all, contained in any part of the animal kingdom, (honey certainly belonging to the vegetable,) except in milk, and in the urine, during the fingular difeafe called "diabetes mellitus."

Pure fugar appears either in a regularly cryftallized form, or in fhining white cryftallized grains. Both in candy and loaf it is hard and brittle, inodorous and fweet. If hard loaf-fugar be rubbed in the dark, it is very luminous. With the nitric acid it is convertible chiefly into the oxalic acid. It is very foluble both in water and alcohol. Melaffes, which are conftituted chiefly of the uncryftallizable parts of the juice of the fugar-cane, and which Prouft has denominated liquid fugar, are more foluble in alcohol than fugar. Sugar requires only its own weight of water at 48° for its folution; and when united at a higher temperature with a fmaller quantity, it remains diffolved and forms a fyrup. The watery folution, mixed with mucilaginous, farinaceous, or other matters, readily enters into the vinous fermentation; whence it is inferred, by confidering that the ftrength of the liquor and quantity of alcohol produced depend on the quantity of fugar, that the moft effential part of the procefs of vinous fermentation is the converfion of fugar into alcohol. Four parts of boiling alcohol diffolve one part of fugar; but a moiety of fugar again feparates by reft in cryftals. Oils readily combine with fugar, and the mixture is mifcible with water. Lime and the fixed alkalies unite with fugar, and form compounds, without any fweet tafte. The concentrated ftrong acids diffolve and decompofe fugar, but the weaker fimply diffolve it; and the alkaline and earthy hydro-fulphurets, fulphurets, and phofphurets, decompofe it, and refolve it into a fubftance refembling gum. Its ultimate conftituent parts, according to Lavoifier, are 64 of oxygen, 28 of carbon, and 8 of hydrogen, in 100 parts.

Sugar melts at a heat confiderably above that of boiling water, and forms a blood-red vifcid fluid, which, cooled, has a flavour of empyreuma, not ungrateful, mixed with the natural fweetnefs. When melted, it takes fire from a lighted fubftance, and burns with a ftrong red flame, and a penetrating odour, which excites coughing, and is owing to the production of an acid.

If fugar be diftilled *per fe* from a glafs retort with a heat gradually increafed to rednefs, and the products be carefully collected, they will be found to be, firft, a coloured liquor, ftrongly acid and pungent, called the "pyromucous." A large quantity of gas comes over at the fame time, which is hydro-carbonat mixed with a little carbonic acid; and a very pure charcoal is left behind, which burns away in the open air without leaving any refidue. Neither azot, ammonia, nor lime, nor any other fubftance, is obtained in this procefs, whence it appears that fugar is one of the pureft hydro-carbonous oxyds known.

The actual chemical differences between mucilage and fugar, as ftated by Mr. Cruikfhank, are the following: fugar is foluble both in water and alcohol, and cryftallizable from either folution; but mucilage is infoluble in alcohol, and refufes to cryftallize from its watery folution: 480 grains of fugar yielded by diftillation 120 grains of charcoal, 270 grains of liquid pyromucous acid, 41 ounce-meafures of carbonic acid gas, and 119 ounce-meafures of hydro-carbonat gas:—the fame quantity of gum arabic yielded 96 grains of charcoal, 210 grains of pyromucous acid, 93 meafures of carbonic acid, and 180 of hydro-carbonat. It alfo gave about 10 grains of lime, and the acid, when faturated with lime, gave out a little ammonia; and hence it appears, that lime and azot are fubftances that belong to mucilage, and not to fugar. The habitudes of each fubftance with nitric acid differ alfo confiderably. When gum arabic (*e. g.*) is heated with nitrous acid only till nitrous gas begins to be difengaged, a quantity of white infoluble matter precipitates, which is the "mucous" acid, and the refidue is "malic" acid, which a farther addition of the nitric converts into oxalic. But fugar is changed into oxalic, or malic and oxalic acid, without the production of any mucous acid. The quantity of oxalic acid produced from a given weight of fugar with nitric acid alfo exceeds that yielded by the fame weight of mucilage with the fame proportion of acid. In the fpontaneous changes, alfo, fugar and mucilage differ effentially: fugar being the effential material of the vinous fermentation; but mucilage is incapable of this procefs when pure, and appears to contribute little to the generation of alcohol, when in combination with fermenting materials.

From the known properties of fugar, it is fuppofed to unite the unctuous part of the food with the animal juices: hence fome have concluded, that it is nutritive to animals, and increafes corpulence; others have afcribed to it a contrary effect, as it is faid to prevent the feparation of the oily matter, which forms fat, from the blood; and others, again, have charged it with rendering the juices thicker and more fluggifh, retarding circulation, obftructing the natural fecretions, and thus occafioning or aggravating fcorbutic, cathartic, hypochondriacal, and other diforders. However, experience feems to fhew, that the moderate ufe of it is at leaft innocent.

Profeffor Murray, who has treated this fubject very elaborately, thinks that by the fermentation which fugar undergoes in the ftomach, and by its relaxing refolvent faponaceous qualities, as well as by the acid which it contains, it rather tends to emaciate than to fatten the body; and in this opinion he obferves that he has the authority of Boerhaave, who fays, if this fweet be taken in large quantities it produces emaciation, by diffolving too much of the animal oil. He is therefore much furprifed, that Mr. John Hunter fhould lately recommend fugar and honey as the beft reftoratives to thofe fuffering from great debility by a long courfe of mercury. What may be the effects of fugar in this refpect in its refined ftate may be difficult to determine; but in its crude ftate there can be no doubt of its affording a confiderable fhare of nourifhment, both as combined in various vegetable matters, and as feparated by art. Thofe animals which wholly feed upon it in the fugar iflands, become remarkably corpulent; and the negro children, whofe diet happens fometimes for a feafon to be confined to melaffes, are eafily diftinguifhed from others by their fuperior bulk; they are, however, more difpofed to fuffer by worms, and are likewife lefs active and healthy.

Sugar however appears, by the experiments of feveral writers, to prove deleterious to various kinds of worms,

either by immerfing them in a folution of fugar, or fprinkling it upon their bodies; and twenty grains of lump-fugar forced into the ftomach of a frog, produced immediate torpor and death, which followed in the courfe of an hour: it alfo proved fatal to pigeons, and to the gallinæ kind, but not to fparrows; and with fheep and dogs it had no other effect than that of a cathartic.

Sugar may certainly be taken into the ftomach in pretty large quantities, without producing any bad confequences; though proofs are not wanting of its mifchievous effects, in which, by its attenuating and diffolving the fluids, and relaxing the folids, debility and difeafe are faid to have been produced. Stark for many days took from four ounces of fugar, to eight, ten, fixteen, and even twenty, with bread and water, by which naufea, flatus, ulceration in the mouth, with rednefs and tumefaction of the gums, oppreffion, purging, pain, and rednefs of the right noftril, bleeding at the nofe, and livid ftreaks over the right fcapula, were produced. We are alfo told that a boy, who was much affected by acidity of the ftomach, in a fhort time greedily ate a large quantity of lump-fugar; foon afterwards he was taken ill, and the next morning found dead in his bed. Upon examining his body, red fpots, and other marks of a diffolved ftate of the blood, were difcovered. What degree of credit ought to be given to thefe and other cafes of the like kind, we leave to the judgment of our readers: but that the liberal ufe of fugar to many ftomachs has greatly impaired the digeftive powers, and laid a foundation for various complaints, is highly probable. At the fame time we muft admit, that feveral indulge largely in this article, if not with advantage, at leaft with impunity.

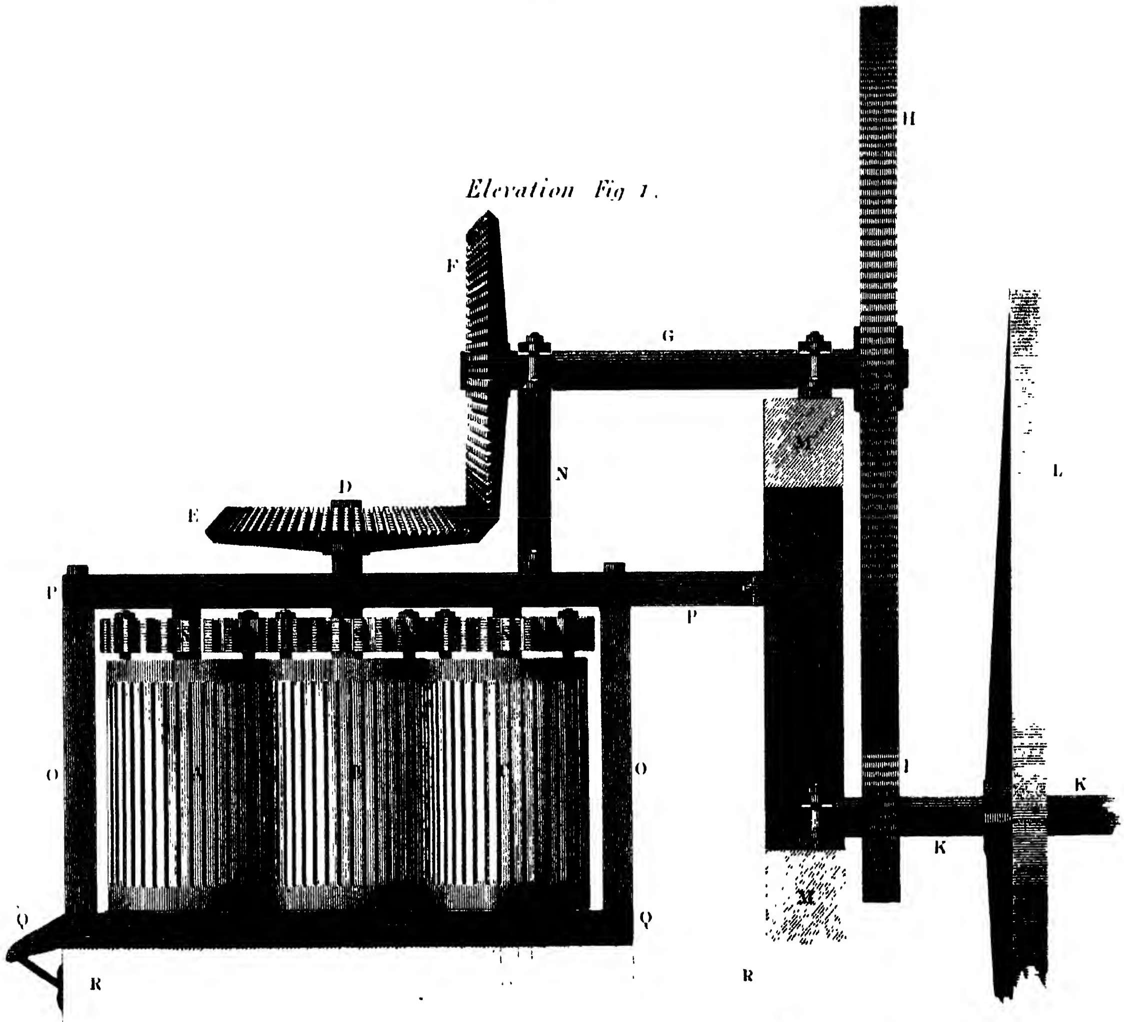
As a medicine, fugar cannot be confidered to poffefs much power. Dr. Cullen claffes it with the attenuantia; and Bergius ftates it to be faponacea, edulcorans, relaxans, pectoralis, vulneraria, antifeptica, nutriens. In catarrhal affections, both fugar and honey are frequently employed: it has alfo been advantageoufly ufed in calculous complaints; and from its known power in preferving animal and vegetable fubftances from putrefaction, it has been given with a view to its antifeptic effects. The candy, by diffolving flowly in the mouth, is well fuited to relieve tickling coughs and hoarfenefs. The ufe of fugar in various medicinal compofitions is too obvious to require being particularly pointed out.

Raw fugar and melaffes, by virtue of their oily or treacly matter, prove emollient and gently laxative. The cryftals or candy are moft difficult of folution, and hence are moft proper where this foft lubricating fweet is wanted to diffolve flowly in the mouth, as in tickling coughs and hoarfenefs. Refined fugar, externally applied, is efcharotic.

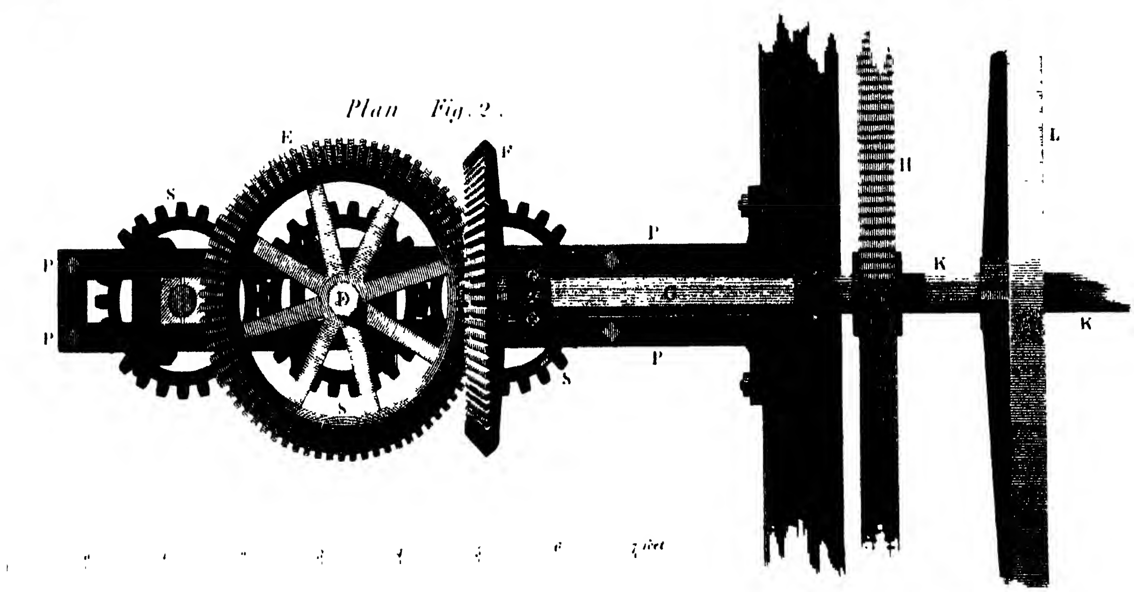
Coarfe fugar, in which there is more oil than in refined fugar, is recommended as a good medicine in collyria for difcharging ulcers of the cornea, in which aftringents are hurtful. Aikin. Lewis. Woodville.

SUGAR MILL

Elevation Fig 1.



Plan Fig. 2.



Drawn by J. Fa[illegible]

Published as the Act directs 181[illegible] by Longman Hurst Rees Orme & Co. Paternoster Row.

Engraved by W. Lowry.

Sulphuric Acid

SULPHURIC Acid, *Vitriolic Acid*, or *Oil of Vitriol*, is formed by oxygen and fulphur ; but it is alfo found that water is effential to the exiftence of this acid.

In the moft concentrated ftate in which fulphuric acid can exift, it is a tranfparent, colourlefs, denfe liquid, of an oily confiftence, and greafy to the touch. Its tafte is very cauftic, and fo extremely four, that a few drops only will render a pint of water too four to drink. It has no fmell, except when it is contaminated with animal or vegetable matter, the fmalleft quantity of which difcolours it. When dropped on thefe fubftances it deftroys their texture, and leaves a black mark. It changes moft vegetable blues to red, and manifefts other qualities of acids in a very eminent degree.

The fixity of fulphuric acid is very confiderable: when in the ftate of common oil of vitriol, it requires nearly a red heat for its vaporization; and though when diluted with water it will boil at a confiderable lower temperature, yet little elfe than water is driven off, and the acid becoming more and more concentrated, requires a continually increafing heat to keep up its ebullition, till it arrives at the degree neceffary for the volatilization of the acid itfelf.

Sulphuric acid freezes or cryftallizes by expofure to cold, and it appears to congeal with more eafe when moderately concentrated than when it is diluted: this remarkable circumftance was firft pointed out by the duc d'Ayen, was then confirmed by Morveau, and has fince been treated at large, and in a very fatisfactory manner, by Mr. Keir. (Phil. Tranf. for 1787, p. 267.) This accurate obferver found that fulphuric acid of the fpecific gravity of 1.78, congeals at about 40° Fahr.; but that if the denfity is either increafed or diminifhed, a greater cold is required for its congelation. Proceeding from the above denfity in each direction, he found that fulphuric acid at the fpecific gravities of 1.786 and 1.775, or at any intermediate denfity, freezes when expofed to the cold of melting fnow; that if the energy of the freezing mixture be increafed by the addition of common falt, it will congeal fulphuric acid at the fpecific gravities of 1.841 and 1.75, or at any intermediate denfity; but that acids at the fpecific gravities of 1.815 on the one hand, and 1.745 on the other, continue fluid. Sulphuric acid while freezing contracts confiderably in its dimenfions; fometimes it forms a confufed mafs, but often fhoots into large regular cryftals in the form of oblique truncated octohedrons, or compreffed hexahedral prifms, terminated by hexahedral pyramids.

Sulphuric acid attracts water with great avidity, and accumulates in bulk. This takes place even in a ftopped bottle, if the ftopper does not fit very tight.

If fome of the fulphuric acid at the ufual denfity of 1.845 be mixed with one-fourth of its weight of water, the temperature of the mafs inftantly rifes to near 300° Fahr. and a mutual penetration takes place, the denfity of the compound being greater than the mean denfity of its ingredients. If even four parts of fulphuric acid and one of ice, both at the temperature of 32°, be mixed together, the heat of the mafs will rife to 212°; but if the proportion of ice be increafed confiderably, the caloric neceffary to the liquid ftate of the mixture will exceed that which is extricated during the combination of the ingredients, and cold will be produced; thus, if four parts of ice and one of acid at 32° be mixed together, the temperature of the mafs will be cooled down to − 4°. But in all cafes where concentrated fulphuric acid is employed in the compofition of freezing mixtures, there is at the moment of their combination, as Beaumé has well obferved, a very fenfible production of heat, which muft materially diminifh the frigorific effect; thus, according to the able chemift laft mentioned, (Chem. Exper. i. p. 219.) if one part of fulphuric acid at the common temperature, and four parts of ice, be mixed together, the firft effect is to raife the thermometer in

an inftant to 94° Fahr., from which it finks as fpeedily to 32°. But if the acid has been previoufly diluted with water, the temperature finks on the addition of ice to 5° Fahr. without any previous heat having been excited. So powerful is the affinity of fulphuric acid for water, that it will abforb moifture with great rapidity from the air, fo as in a very few days to double or treble its weight. Even a boiling temperature, when the acid is moderately concentrated, will not counterbalance this ftrong tendency; hence it is that fulphuric acid cannot by boiling in an open veffel, be concentrated nearly fo much as by diftillation in a clofe apparatus.

The fpecific gravity of this acid varies from 1.85 to the moft dilute acid, depending upon the water it contains.

The following table of the fpecific gravities of fulphuric acid of different ftrengths, is taken from Mr. Dalton's New Syftem of Chemical Philofophy.

TABLE of the Quantities of real Acid, in 100 Parts of Sulphuric Acid at 60°.

Atoms of Acid Water.	Acid per cwt. by Weight.	Acid per cwt. by Meafure.	Specific Gravity.	Boiling Point.
1 + 0	100	Unknown.	Unknown.	Unknown.
1 + 1	81	150	1.856	620°
	80	148	1.849	605
	79	146	1.848	590
	78	144	1.847	575
	77	142	1.845	560
	76	140	1.842	545
	75	138	1.838	530
	74	135	1.833	515
	73	133	1.827	501
	72	131	1.819	487
	71	129	1.810	473
	70	126	1.801	460
	69	124	1.791	447
1 + 2	68	121	1.780	435
	67	118	1.769	422
	66	116	1.757	410
	65	113	1.744	400
	64	111	1.730	391
	63	108	1.715	382
	62	105	1.699	374
	61	103	1.684	367
	60	100	1.670	360
1 + 3	58.6	97	1.650	350
	50	76	1.520	290
	40	56	1.408	260
1 + 10	30	39	1.300	240
1 + 17	20	24	1.200	224
1 + 38	10	11	1.100	218

The acid at 100, at the head of the column, is the real acid, or that which combines with different bafes, to form the falts called fulphates. It is difficult to fay whether it does really exift in a feparate ftate. Mr. Dalton fays it is formed when nitrous gas, oxygen, and fulphurous acid, are mixed together, and appears in fhining cryftals, like hoar froft. On the other hand, fir Humphrey Davy afferts, that when nitrous acid gas, and fulphurous acid gas, are mixed in a glafs globe, and the gafes perfectly free from moifture, no fulphuric acid is formed. But if a drop of water be introduced, there will be an immediate condenfation, and a beautiful white cryftalline folid will line the interior of the veffel: whereas, if the globe contain plenty of water, nitrous gas will be given off with great violence, and the water will be found to be a folution of oil of vitriol. We fhould feel fome delicacy in doubting the accuracy of either of thefe authorities, but it is neverthelefs certain, that one of them has been deceived. The experiments were certainly a little different. Mr. Dalton employed nitrous gas and oxygen, which we fhould imagine could not give a refult different from fir Humphrey's, who employed the nitrous acid ready formed. Both thefe chemifts feem to agree, that the acid of the fpecific gravity 1.85 contains an atom of water. This acid is the ftrongeft that can be made by concentration, for at its boiling point, which is 620°, the acid and water rife together.

It will be perceived from the table, that the fpecific gravity varies very little with the firft portions of water; and hence it is a very uncertain teft of the value of very ftrong acids. We have generally obferved, that thofe who keep an hydrometer for the purpofe of affaying the oil of vitriol, hardly ever complain of its want of fpecific weight.

Mr. Dalton recommends the boiling point of ftrong acids as a better teft of their ftrength. The table fhews, that when the quantity of real acid varies one *per cent.* the fpecific gravity is only changed in the third decimal place; but the boiling point varies as much as 15°. This points out a fimple method of affaying fulphuric acid with much greater precifion than by the hydrometer. An inftrument might eafily be conftructed for this purpofe. It fhould confift of a fmall platina cup, capable of holding as much fulphuric acid as will cover the bulb of a mercurial thermometer. An upper part may be attached to this cup, to contain the ftem of the thermometer, and at the fame time to guard it from the heat of the fire on which the cup is placed.

The cup of platina, being filled with the acid to be tried, may be placed on a fmall charcoal fire, or a fand-bath, or indeed a clear common fire, till the acid boils, when it will fhew the ftrength of the acid, by degrees marked upon the fcale of platina; the degrees being expreffions of the fpecific gravity, inftead of degrees of temperature. The firft column in the table gives the relative number of atoms of water and acid for different ftrengths. The way in which the acid mixes with water as well as with the folutions of falts, feems to favour the idea of their proportions being indefinite. But this is merely an apparent anomaly. The acid may combine with one, with two, with three, and perhaps a greater number of atoms of water, but this number may ftill be limited. An acid weaker than the limited number of atoms of water would give, is conftituted by the limited compound becoming equably difperfed through a mafs of water, the excefs of water not being combined but merely mixed. Such may alfo be the cafe with folutions of falts.

That the acid and the water are combined chemically, the condenfation of volume, and change of temperature, clearly prove; and in the prefent ftate of chemiftry, it is not lefs clear that the proportions of compounds are limited.

Sulphuric acid is conftituted by one atom of fulphur 15, and three atoms of oxygen 22.5, making its atom 37.5. The ftrongeft liquid acid, as will be feen by the table, will confift of an atom each of acid and water, which will be $37.5 + 8.5 = 46$: the fpecific gravity of this is 1.85. Acids of this ftrength, down to 1.8, have the name of oil of vitriol, from the circumftance of this acid being formerly diftilled from green vitriol. That the component parts of fulphuric acid are fulphur and oxygen, may be demonftrated either by analyfis or fynthefis; thus, if fulphur be

digested with nitric acid, nitrous gas will be given out from the decomposition of the acid, while the oxygen, the other element, will combine with the sulphur, and form with it sulphuric acid; on the other hand, if sulphate of soda be mixed with charcoal and exposed to a red heat, the sulphuric acid is deoxygenated by the superior affinity of the charcoal; carbonic acid and carbonous oxyd are produced, and the sulphate of soda is found to be converted into sulphuret of soda, from which the sulphur may readily be procured by solution in water, and the addition of an acid.

But though the elements of sulphuric acid are ascertained, much doubt still exists with regard to their relative proportion.

Several methods have been employed for ascertaining these proportions. Lavoisier, for this purpose, placed a given weight of purified sulphur in a receiver, with a little water to absorb the acid produced; then setting fire to the sulphur, he supplied it with oxygen gas of known purity, till the combustion ceased: then by ascertaining the weight of sulphur burnt, and of oxygen gas consumed, he inferred that sulphuric acid was composed of 71 parts of sulphur to 29 parts of oxygen. Berthollet, having ascertained that nitre and sulphur, in the proportion of four parts of the former to one of the latter, when heated in a retort, re-acted on each other quietly and without explosion, mixed together 288 grains of nitre, and 72 grains of sulphur, and heated the mixture in a glass retort till the emission of nitrous gas entirely ceased. During the process, 12 grains of sulphur had sublimed unaltered, and 228 grains of sulphate of potash were produced by the combination of the alkaline base of the decomposed nitre with the newly produced sulphuric acid. Now, according to Kirwan, sulphate of potash is composed of 45.2 sulphuric acid, and 54.8 potash; therefore, out of the 228 grains of sulphate of potash, 103 grains were sulphuric acid, composed of $72 - 12 = 60$ grains of sulphur, and 43 grains of oxygen: hence 100 parts of sulphuric acid consist of

Sulphur	- - -	58.2
Oxygen	- - -	41.8
		100.0

Another method, followed by Berthollet, Thenard, and Chenevix, and which some have thought to be upon the whole the best, is to digest a given weight of sulphur in nitric acid, till it is completely dissolved and acidified, (which, if performed with care, may be effected without the production of any sulphurous acid,) then to add a solution of nitrate or muriate of barytes as long as any precipitate takes place, by which the whole of the newly-formed sulphuric acid will combine with barytes into an insoluble salt; then to edulcorate and ignite the sulphated barytes, and from its weight to deduct that of the barytic base; the remainder consequently will indicate the amount of sulphuric acid produced, from which, by subtracting the known weight of sulphur, we get by inference that of the oxygen.

By compounding the results arising from the experiments of several skilful chemists, the composition of sulphuric acid seems to be, according to

		Klaproth.	Thenard.	Chenevix.
Sulphur	-	24.3	37.4	41.2
Oxygen	-	75.7	62.6	58.8
		100	100	100

By another Statement.

		Klaproth.	Thenard.	Chenevix
Sulphur	-	43.2	57.4	61.5
Oxygen	-	56.8	42.6	38.5
		100	100	100

By a third Statement.

Sulphur	-	41.8	55.56	59.1
Oxygen	-	58.2	44.44	40.9
		100	100	100

Muriatic acid gas combines readily, and in abundance, with sulphuric acid; and the compound acquires a brownish tinge, and, when exposed to the air, emits dense white fumes of muriatic acid gas, probably mixed with a little sulphuric acid, as their odour is more pungent and suffocating than that of simple muriatic acid. The nitric and sulphuric acids unite readily together, either by direct mixture, or by adding a little nitre to sulphuric acid. This compound is of considerable use for recovering the silver from clippings and other refuse of the manufactories of silver-plate. Sulphuric acid absorbs, by agitation, a considerable quantity of red nitrous vapour, and in consequence acquires a light blue colour. The mixture, when exposed to the air, gives out a white vapour. If water is added, the great heat that is thereby generated causes a very rapid and copious emission of the nitrous vapour, and sulphuric acid and water alone remain behind. Sulphuric acid, thus impregnated with nitrous vapour, after a time becomes nearly colourless, and then concretes into solid crystals. In this state, when dropped into water, it acquires a green colour, and both the crystals and water sparkle with the spontaneous and copious production of nitrous gas. When the crystals are simply exposed to heat, they melt, emit a dense red fume, and, after the nitrous vapour is thus driven off, the residue is common sulphuric acid.

Concentrated sulphuric acid, even when cold, acts in a very striking manner on most kinds of vegetable and animal matter. If a piece of paper or straw, for example, be immersed in sulphuric acid, the texture of the straw is speedily broken down, it acquires a deep black colour, and is diffused through the acid in a state of half solution. This phenomenon, however, does not take place, as is generally supposed, on account of the re-action of the sulphuric acid on the carbon and hydrogen, producing sulphurous acid, but from the strong affinity of the acid for water; in consequence of which, the oxygen and hydrogen of the vegetable matter combine together into water, while the carbon is precipitated.

Sulphuric acid combines with all the metallic oxyds, with the alkalies, and all the earths except silex, forming an important genus of salts, called in the reformed nomenclature *sulphates*; which see.

The following is the order of the affinities of sulphuric acid: barytes, strontian, potash, soda, lime, magnesia, ammonia, glycine, yttria, alumine, zircon, metallic oxyds.

When sulphur is burnt in oxygen, whether in the pure gas or in the atmosphere, it forms only sulphurous and not sulphuric acid; but if the sulphurous acid be absorbed by water, and exposed to the air for some time, the latter absorbs oxygen, and is converted into sulphuric acid. Hence sulphuric acid cannot be formed by the mere combustion of sulphur; a circumstance which renders the process of manufacture much less simple than it otherwise might be.

Sulphuric acid is at present formed by mixing together one part of nitre and seven parts of sulphur. This mixture is placed in a chamber, lined with lead. When these materials are set on fire, the nitre facilitates the burning of the sulphur by the oxygen it affords; but it does not furnish sufficient to convert the sulphur into sulphuric acid. The 7 parts of sulphur will require 10.5 of oxygen for that purpose, but the nitre employed with it can furnish no more than .225, supposing the nitric acid to be reduced to the state of nitrous gas. This is so small a portion of the whole, that some other source must be explored, which is doubtless the atmosphere.

The combustion of the sulphur, which is facilitated by the presence of the nitre, first converts the sulphur into sulphurous acid; which, from its gaseous form, would soon be dissipated, if it were not condensed by its conversion into sulphuric acid. When a portion of the nitric acid of the nitre is decomposed by the sulphur, nitrous gas is evolved; but in its ascent, it meets with the oxygen in the chamber, and is converted into nitrous acid gas, which appears in red fumes. The new-formed substance can now dispose of an atom of oxygen, which the sulphurous acid is wanting to convert it into sulphuric acid. The bottom of the leaden chamber is covered with water to the depth of two or three inches. This water seems to answer a double purpose; in first facilitating the action of the nitrous acid gas upon the sulphurous acid, and then dissolving the sulphuric acid as it is formed. When the nitrous acid gas has disposed of its atom of oxygen, it returns to the state of nitrous gas; and in rising, unites with more oxygen, which it again gives to sulphurous acid; thus continuing its receiving and giving office, till it is accidentally dissipated through the same apertures which admitted the common air. A necessary connection between the chamber and the atmosphere will appear obvious. Atmospheric air must be admitted for the combustion of the sulphur, and to afford oxygen to the nitrous gas; and through the same, or some other opening, the residual azote must be returned into the open air. Some nitrous gas, and probably nitrous acid gas, will escape at the same time. If the latter were not the case, a constant decomposition of nitre by the sulphur would not be necessary. The theory of this process has been given by the French chemists, Chemint and Desormes. Sir Humphrey Davy objects to it in some degree. He holds, that the union of the oxygen of the nitrous acid with the sulphurous acid does not take place till they come in contact with water; the latter, according to his opinion, being essential to the constitution of the sulphuric acid. If the above theory be correct, a simpler mode of manufacture might be pointed out. The combustion of the sulphur might be so managed, as to furnish the sulphurous acid without loss, but mixed with azote.

From another source nitrous gas and atmospheric air may be furnished. These with the other products meeting where water is present, ought to form sulphuric acid in a very small space compared with the large chamber at present employed. The gases, by this means, might be furnished in proportions so exact, that nothing but azote would escape.

The acid and water which cover the floor of the chamber now only arrive at a certain strength, which is very far short of that required. At that strength it is drawn off, and concentrated by evaporation. This used to be performed in glass retorts, which are very liable to break. If this is not performed in a vessel from which there is but a small opening, the acid would not part with so much of its water, and its concentration would be limited at a very inferior strength to that used for most purposes. Dr. Wollaston has introduced vessels for the concentration of oil of vitriol made of platina: they are very expensive, but answer the purpose admirably. Some manufacturers use leaden vessels for this purpose.

Sulphuric acid is employed extensively in bleaching, with the oxymuriatic acid, and in dyeing. It is the cheapest and most useful acid for cleaning the surface of plates of silver, copper, and iron, by dissolving their oxyds.

The sulphuric acid is said to have been found by Baldassari, in a concrete state, lining a grotto in mount St. Amiato, in Tuscany: it also occurs in the crevices of volcanic mountains, and dissolved in some mineral waters. But the sulphuric acid of commerce is obtained either from the distillation of sulphate of iron, or from the combustion of sulphur. We shall here subjoin a brief account of both methods, referring to Aikin's Dictionary of Mineralogy, &c. for farther particulars.

Sulphate of iron, or green vitriol, consists of sulphuric acid, water, and oxyd of iron: by proper methods, the acid may be separated from the other ingredients of the salt; and this continued to be the only origin of sulphuric acid in the great way, till the discovery, by the manufacturing English chemists, of the art of preparing it by the combustion of sulphur. As this latter discovery has not, however, as yet entirely superseded the former, we shall give an account of both, beginning with the most ancient.

Sulphuric acid is thus prepared at Bleyl, in Bohemia. A long horizontal furnace or gallery of brick-work is constructed, capable of receiving a number of retorts: the retorts themselves are pear-shaped vessels, with a slightly curved neck, by which they fit into earthen receivers nearly of the form of common retorts. The whole apparatus being prepared, each retort is charged with three pounds of sulphate of iron, previously calcined at a full red heat, and the fire is lighted. The first effect of the heat is to drive off the moisture absorbed by the vitriol in the interval between its calcination and distillation: this phlegm, being only very slightly acidulous, is allowed to escape; and when it ceases to come over, the receiver with a little water in it is luted on to the retort. The fire is now raised, and kept up brisk for 32 hours, during which time the acid rises in the form of dense white vapours, which fill the receiver, and are there absorbed by the water. These vapours being at a high temperature, soon render the receiver very hot: hence the workmen judge of the termination of the process, by the receiver becoming cool, in consequence of the vapour ceasing to rise. The red oxyd of iron, or colcothar, is now taken out of the retort, and its place is supplied with a fresh charge of calcined vitriol: the distillation then takes place as already described, except that the former produce of acid is not emptied out of the receiver, and, therefore, there is no occasion to add any water. If the retort is well made, and carefully luted all over, it will last for three successive distillations, and the quantity of acid obtained is nearly equal to half the weight of the calcined sulphate.

If the acid be examined at different periods of the distillation, it will be found to be more and more dense, according to the violence of the fire required for its extrication: the latter portion, if received in a separate vessel, will generally congeal upon cooling; hence it is called *glacial sulphuric*

This acid used to be, and perhaps is still, prepared at Nordhausen, in Saxony: it is of a dark brown colour, and exhales, when exposed to the air, abundance of dense, white, suffocating vapours; its usual specific gravity is = 1.95. For other properties, see Aikin, *ubi supra*.

From the facts which he has recited it seems probable, that the essential difference between the common and glacial acid is, that the latter, from the mode in which it is prepared, contains a smaller portion of water than the former, and that to this is owing both its volatility and property of congelation. It is incidentally mixed with sulphurous acid, but the presence or absence of this does not appear to be of any material importance.

The sulphates of copper and zinc have occasionally been employed, instead of the sulphate of iron, but with a manifest disadvantage, both because they are dearer than the latter salt, and because they require a higher and longer continued heat to drive off the whole of the acid.

The following is the usual method of manufacturing sulphuric acid from the combustion of sulphur. A chamber is constructed of frame-work, and lined with strong sheet-lead; the only aperture is a small door, made to shut very close, the bottom of which is a little higher than the floor of the chamber. Water is poured into this chamber, till it rises to the height of an inch or two upon the floor, and a stand is introduced, on which is placed an earthen pot containing a few pounds of sulphur and nitre, in the proportion of from eight to ten of the former to one of the latter. This mixture is set fire to by means of a red-hot iron, and the door is immediately closed. At the expiration of about six hours, a second charge of sulphur and nitre is introduced, which after a similar interval is replaced by a third, and so on without intermission for a fortnight or three weeks. At the end of this period, the water in the chamber is sufficiently acidulated; it is accordingly transferred to a leaden boiler, where the greater part of the water is evaporated. In proportion, however, as the acid becomes more concentrated, it is more disposed to corrode and dissolve the lead of the boiler; therefore, before this degree of concentration takes place, the liquor is transferred into large green glass retorts, where a degree of heat is applied sufficient to drive off almost the whole of the water. As the acid becomes stronger, it also becomes clearer and less coloured, in consequence of a portion of acid re-acting on the impurities with which it is tinged, and thus destroying them. When the acid is thus brought to the required density and clearness, it is poured out of the retorts into large globular glass bottles, surrounded with wicker-work stuffed with straw, called *carboys*, and is then brought into the market, under the name of *oil of vitriol.*

The sulphuric acid obtained from the distillation of green vitriol exists ready formed in the salt: its extrication is a perfectly simple process, and the only impurities that it can possibly contain are sulphurous acid, and a very minute portion of oxyd of iron, and of the earth of the retort. When loaded with sulphurous acid, it has a suffocating odour, and, when exposed to the air, gives out a white vapour like strong muriatic acid. It used formerly to be sold in this state by the name of *fuming oil of vitriol,* and was further distinguished by its property of congealing into a soft ice, at a very moderate degree of cold. By dilution with a little water, and subsequent boiling for few minutes in a glass vessel, the sulphurous acid is driven off, and the residual fluid is common sulphuric acid in a state of very considerable purity.

When the method of producing sulphuric acid by the combustion of sulphur and nitre was first discovered, the apparatus employed was a series of very large glass balloons, at the bottom of each of which was a little water to condense the vapour; only a small quantity of the mixture could be burnt at once, and constant superintendance was necessary to supply the balloons with fresh charges of the materials. In order to save much of this manual labour, and the heavy loss arising from the frequent fracture of the vessels, leaden chambers were made use of, which, besides requiring less attendance, and being upon the whole cheaper, rendered it easier for the manufacturer to extend his establishment to any required magnitude. These chambers are of various construction: the most simple and in most general use are furnished only with two apertures, namely, a small door, by which the water and the sulphur and nitre are introduced, and a leaden pipe with a stop-cock, by which the water, when acidulated, is drawn off: other chambers have besides a few small apertures, for the introduction of atmospheric air during the combustion, and a steam-pipe connected with a boiler, it being found that if the water is introduced in the state of steam, a much more rapid condensation of the acid ensues than in the usual way of proceeding. In some of the best contrived chambers, the combustion of the nitre and sulphur is effected in a separate stove, and the acid vapour thus produced is poured by means of a pipe into the condensing chamber.

There is a good deal of difference among the manufacturers as to the proportion of nitre employed: by some it is made equal to one-fifth of the sulphur, while by others it is not allowed to exceed one-tenth. This, however, appears to be satisfactorily established, that within the above limits the greater the proportion is of nitre, the more easily condensible will the acid vapour be, and the less sulphur will be lost in the form of sulphurous acid gas. If the nitre exceeds one-fifth of the sulphur, the combustion will be so rapid as to drive into the chamber a considerable proportion of sulphur unaltered. It would conduce much to the purity of sulphuric acid, and might probably be found even to be an economical plan, to line the chamber with glass instead of sheet-lead: the general appearance of the chamber would then resemble a green-house, and all the wood-work should be faced internally with glass. A composition of wax, mastich, and fine sand, would form a strong cement for the glass, and little liable to be acted on by acid vapours, more especially if the interstices filled up with it were dusted with powdered glass, or very fine sand, while the cement was yet warm and adhesive. Such a chamber would have the additional advantage of allowing the operator to see what was passing within, without the necessity of opening the door.

The common English sulphur is unfit for the preparation of sulphuric acid, on account of a yellowish-brown colour which it gives to this fluid, and which it is not easy to get rid of. For this reason, the refined Sicilian sulphur is the only kind that is employed in this manufacture, at least in Britain.

Common sulphuric acid may be freed from the sulphates of lead and potash, which it generally contains, by distillation. This, however, though apparently a very simple process, is rather a nice matter to manage, according to the usual method. Sulphuric acid is not capable of being distilled at less than a red heat: when, therefore, the dense hot vapour first comes in contact with the necks of the retort and receiver, it is apt to break them, unless the precaution has been taken of thoroughly heating them by means of a pan of charcoal placed beneath, a minute or two before the distillation commences. All this risk, however, may be avoided, and in some laboratories it actually is so, by connecting the glass body, in which the acid is boiled, with the receiver, by means of a tube of platina. Boiling sulphuric acid has not the least action on this metal, and the vapour, in its passage through, becomes so far cooled and condensed, that it flows into the receiver in drops.

Sulphuric *Acid*, in the *Materia Medica*, is a valuable tonic, aftringent, and antifeptic. Its officinal preparations are the following; *viz. Acidum fulphuricum dilutum; acidum fulphuricum aromaticum; acid. citricum; acid. muriaticum; acid. nitricum; aqua fuper-carbonatis potaffæ; fulphas potaffæ; phofphas fodæ; murias antimonii; ferri fulphas; hydrargyri oxymurias; fub-fulphas hydrargyri flavus; zinci fulphas;* and *æther fulphuricus.*

The *acidum fulphuricum dilutum*, or diluted fulphuric acid of the Lond. Ph., is obtained by adding a fluid-ounce and a half of fulphuric acid gradually to 14 fluid-ounces and a half of diftilled water, and mixing. The Edin. Ph. directs one part of fulphuric acid to be mixed with feven parts of water. The Dub. Ph. orders 2 oz. by weight of fulphuric acid to be mixed *gradually* with 14 oz. by weight of diftilled water, and the mixture to be fet afide to cool; then the clear liquor to be poured off. The fp. gr. of this acid is to that of water as 1090 to 1000. The tonic and antifeptic powers of this acid render it extremely ferviceable in low typhoid fevers, dyfpeptic affections, diabetes, convalefcencies, and in cutaneous eruptions. It reftrains the colliquative fweats which attend hectic; locally applied, it is a common and ufeful adjunct to gargles in cynanche, and to check falivation; and as a refrigerant, it is given with certain benefit in paffive hæmorrhages, from whatever part they may arife. In the firft-mentioned cafes the diluted acid may be combined with infufions of cinchona or other vegetable bitters, and aromatics; and in the latter, with infufion of rofes, mucilage, or fimple water fweetened with fyrup. The ufual dofe is from ♏ x to ♏ xxx, but in malignant eryfipelas, with a tendency to hæmorrhagy, it has been given to the amount of f℥j in twenty-four hours; and it has alfo been given with evident advantage, fays Thomfon, to the fame amount, in violent uterine hæmorrhages.

The *acidum fulphuricum aromaticum*, or aromatic fulphuric acid of the Edin. Ph., is prepared by dropping 6 oz. of fulphuric acid gradually into 2 lbs. of alcohol; digefting the mixture in a covered veffel with a very gentle heat for three days; then adding of cinnamon bark, bruifed, 1½ oz. and ginger root, bruifed, 1 oz.; digefting again in a clofe veffel for fix days, and filtering through papers placed in a glafs funnel. The odour of this oil, which is generally regarded as an imperfect ether, is peculiar and aromatic, and its tafte gratefully acid: it is limpid, and of a brownifh colour. This is an agreeable mode of exhibiting fulphuric acid in dyfpepfia, chronic afthma, and moft of the complaints for which the diluted acid has been found ferviceable. The dofe may be from ♏ x to ♏ xxx in bitter infufions, or any convenient fluid vehicle, given three or four times a day.

The *acidum citricum*, or citric acid of the London Ph., is obtained by taking of lemon juice a pint, prepared chalk an ounce, or a quantity fufficient to faturate the juice, and nine fluid-ounces of diluted fulphuric acid: add the chalk by degrees to the lemon juice heated, and mix them; then pour off the liquor. Wafh the citrate of lime which remains in repeated portions of water, and then dry it. On the dried powder pour the diluted fulphuric acid, and boil for ten minutes; exprefs the liquor ftrongly through a linen cloth, and filter it through paper. Evaporate the filtered liquor with a gentle heat, fo that cryftals may form as it cools. To obtain the cryftals pure, diffolve them in water a fecond and a third time; filter each folution, boil it down, and put it apart to cryftallize. (See Citric *Acid.*) The folution of this acid in water, in the proportion of ℨj of the cryftals to oj of water, anfwers nearly all the purpofes of recent lemon juice; and is even preferable for forming the common effervefcing draught with fubcarbonate of potafs. A folution of ℈ij in oj of water, fweetened with fugar that has been rubbed on frefh lemon-peel, forms a grateful refrigerant beverage, refembling lemonade, and equally ufeful in febrile and inflammatory complaints. It is probable that the cryftallized acid may be equally ufeful in fcurvy as the frefh juice of the fruit; but we have not heard whether this point has yet been afcertained.

Acidum muriaticum, or muriatic acid of the London Ph., is prepared by taking of muriate of foda dried, 2 lbs.; 1½ lb. of fulphuric acid; and 1½ pint of diftilled water; firft mixing the acid with half a pint of the water in a glafs retort; and when the mixture is cold, adding to it the muriate of foda; pouring the remainder of the water into the receiver; and, having fitted to it the retort placed in a fand-bath, diftilling over the muriatic acid into this water, with a heat gradually raifed until the retort becomes red-hot. The fpecific gravity of muriatic acid is to that of diftilled water, as 1.170 to 1.000. The Edinb. Ph. directs to take of muriate of foda, 2 lbs.; of fulphuric acid, 16 oz.; and 1 lb. of water: firft expofe the muriate of foda in a pot to a red heat for a fhort time, and when it is cold, put it into a retort; then pour the acid, mixed with the water and cooled, upon the muriate of foda; and, finally, diftil from a fand-bath with a moderate fire as long as any acid comes over. The Dub. Ph. directs to take of muriate of foda dried, fulphuric acid, and water, of each fix pounds; to dilute the acid with the water, and after it is cold, to add it gradually to the muriate put into a glafs retort; then to diftil the liquor until the refiduum becomes dry. (See Muriatic *Acid.*) This acid is tonic and antifeptic. It has been efficacioufly ufed in typhus fevers, and in fome cutaneous eruptions. It is a common and ufeful adjunct to gargles, in the proportion of from fℨfs to fℨij in f℥vj of any fluid, in ulcerated fore-throats, and cancrum oris; and, in a very highly diluted ftate, ♏ viij in f℥iv of water, it has been recommended as an injection in gonorrhœa.

This acid has even been regarded as an antidote in general fyphilitic affections; but the obfervations of Mr. Pearfon have fhewed this opinion to be erroneous; yet, by its falutary effects on the ftomach and general health, "it is a medicine capable of ameliorating the appearance of venereal ulcers, and of reftraining for a time the progrefs of the difeafe," where it is defirable "to gain a little time, previoufly to the entering on a mercurial courfe." The dofe is from ♏ x to ♏ xx in a fufficient quantity of water.

A very important property of muriatic acid, in the ftate of gas, is the power it poffeffes of neutralizing putrid miafmata, difcovered by Morveau in 1773. It is, therefore, ufed as an agent for deftroying infection in fick rooms and hofpitals, difengaged by pouring fulphuric acid on common falt.

Acidum nitricum. (See Nitric *Acid.*) For the other articles above enumerated, fee Antimony, Iron, Mercury, Potassæ, Salts, Sulphate, &c.

For an account of the *ether fulphuricus*, or fulphuric ether, fee Spirit.

The ethereal oil of the Lond. Ph. is prepared in the following manner. After the diftillation of fulphuric ether, diftil again the remaining liquor with a gentle heat, until a black froth fwells up; then immediately remove the retort from the fire. To the liquor in the retort add water fufficient, that the oily part may float upon it. Let this be fcummed off, and as much lime-water be added to it as will neutralize any acid it may contain; and fhake them together. Laftly, take off the ethereal oil after it is feparated. The oily ethereal liquor of the Dub. Ph. is obtained by taking what remains in the retort after the diftil-

lation of ſulphuric ether, and diſtilling to one half by a moderate heat; the product of both theſe proceſſes is a thick oily matter, of a yellow colour, leſs volatile than ether, but ſoluble both in ether and alcohol. It may be obtained more directly, though leſs economically, by diſtilling ether with a portion of ſulphuric acid. It is uſed for the preparation of the compound ſpirit. See SPIRIT *of Ether*.

Tanning

TANNING, the art of converting the gelatinous part of the ſkins of animals into the ſubſtance called leather, by impregnating it with tannin or the tanning principle, in ſuch a manner as to render it tenacious, durable, and impermeable to water.

It is difficult to ſay at what period the art of tanning was diſcovered. It was doubtleſs known to the ancients in ſome degree of perfection; and it is highly probable that the ſkins of animals were employed by man as a covering long before the art of tanning was known: but they would require in this ſtate to be conſtantly kept dry, as moiſture would ſoon bring them into a ſtate of putrefaction.

The aſtringent matter, which converts the ſkin into leather, abounds in ſo many vegetables in every country, that accident would ſoon lead to ſome method of producing the change. Independent, however, of vegetables, many earthy and metallic ſubſtances have the property of rendering ſkins incorruptible to a certain extent; and ſome mineral waters containing copper or iron will occaſion this change. Hence we may conclude that ſome means of giving preſervation to the ſkins of animals muſt have been known at a very early period.

Though there has been no radical alteration or any great practical improvements in the art of tanning, yet for the laſt twenty or thirty years it has attracted the attention of many celebrated chemiſts and philoſophers in all countries, who have inveſtigated the ſubject with great accuracy and preciſion. Previous to this period we occaſionally find ſome experiments and obſervations by men of ſcience on the materials of tanning, as by the Hon. Charles Howard in 1674, (Phil. Tranſ. vol. ix.) by the abbé Nollet, Geſner, Gleditſch, Buffon, de la Lande, and others, in Mem. Acad. Sc. Paris and Berlin.

In the year 1765, the Society of Arts and Sciences in London granted a premium of 100*l*. for the diſcovery of a method of tanning with oak ſaw-duſt; and in 1795 the Rev. G. Swayne ſuggeſted the uſe of oak leaves. It is unqueſtionably true that all thoſe ſubſtances, and indeed every part of almoſt every vegetable in nature, poſſeſſes a certain portion of the tanning principle; but, excluſive of oak bark and two or three other well-known articles, the quantities of all the reſt added together would be ſo inconſiderable, and the proportion of tannin contained in them ſo inadequate to the purpoſes of manufacture, that, except for philoſophical curioſity and chemical experiment, they are unworthy of notice. As the theories of ſpeculative minds they are ingenious and amuſing, but they afford very little uſeful information on the nature and properties of tannin, and have produced no beneficial reſults in practice.

Deyeux, about 1793, (Annales de Chimie, vol. xvii.) appears to be the firſt chemiſt who ſucceſsfully explained the true principles of tanning; which afterwards, with more practical application, were ſtill further developed by the labours of M. Seguin in 1795. Before his inveſtigation of this ſubject, the theory of tanning was ſtrictly mechanical. The aſtringency of vegetables, which produced the change in the ſkin, was conſidered as a reſinous body, which had the effect of giving firmneſs to the fibres of the ſkin, and rendering it inſoluble.

Seguin ſaw the operation in a chemical point of view: he examined the nature of the proceſs ſcientifically, and diſcovered that the change which the ſkin underwent in the operation of tanning, was the reſult of a chemical union between a ſubſtance furniſhed by the vegetable employed, and the gelatinous part of the ſkin. Theſe principles he confirmed, by combining the vegetable ſubſtance in queſtion with the gelatine of a ſolution of iſinglaſs.

It will be ſeen, from our article TANNIN, that the compound diſcovered by Seguin, and which is precipitated when an infuſion of nutgalls is added to a ſolution of iſinglaſs, is an inſoluble ſubſtance, having many properties common to leather. See Nicholſon's Journal, vol. i. p. 271. 4to.

The practice which M. Seguin founded upon his theory was generally admired. He firſt extracted the tannin from the vegetable, which was oak bark, and applied it to the prepared ſkin in a more concentrated form, with a view to impregnate it as ſpeedily as poſſible with the tannin. This was ſaid to be done with great ſucceſs in one-third of the uſual time, and to have produced ſuperior leather. The fame of this diſcovery ſoon ſpread throughout Europe, and Mr. Deſmond, a man of education and intelligence in this country, took out a patent for the excluſive right of uſing M. Seguin's method of tanning.

Although this proceſs of ſuſpending the hides vertically in a very ſtrong ſolution of bark ſaved much time, yet it was ſoon found to be adapted only to the thickeſt hides uſed for ſole leather, and quite unfit for the lighter kind of ſkins which required flexibility and tenacity. This method, therefore, of Seguin's, however chemical and philoſophical it might appear, did not anſwer in the reſult; and as it was attended with much additional expence, has never been generally practiſed in England.

It was not, however, till 1803, when ſir Humphrey Davy (a name ever to be recorded in the annals of ſcience with gratitude and admiration) began to inveſtigate the ſub-

ject, that the art of tanning was thoroughly underftood, and reduced to fcientific principles. He inftituted a feries of experiments on the various fubftances employed—examined their chemical affinities and agencies—their action upon animal matter, and combination with other bodies—and developed and explained the whole with a fimplicity and perfpicuity which forcibly elucidated the effential principles on which the art depends. If this elucidation has not been productive of any material improvements in the mode of manufacturing leather, it may perhaps be attributed more to the prejudices arifing from long habit, than to any defect in the theory and demonftrations of that enlightened philofopher. And here it may be remarked, that thefe demonftrations and that theory derive additional importance, and are entitled to peculiar attention, from having been ftrongly confirmed and fuccefsfully practifed by an intelligent and refpectable manufacturer (now retired from bufinefs), to whom we are chiefly indebted for this article.

From thefe and other fources of information now open to the public, and from the general diffufion of knowledge among all claffes, the man of fcience and the manufacturer are daily becoming more affimilated to each other; and if the latter fhould be taught to difcard all unfounded prejudices, and to adopt more fcientific principles, there is reafon to believe that the various proceffes of the art of tanning may yet be capable of great practical improvement.

In the two valuable papers which fir Humphrey Davy has given in the Philofophical Tranfactions for 1803, he confiders the procefs of tanning as depending fimply on the chemical union of the tanning principle with the matter of fkin, fo as to form an infoluble compound. He has fhewn that Seguin's quick method of tanning is not the beft; becaufe the exterior ftrata of fkin being perfectly combined with tannin, before the interior ftrata are materially acted upon, thereby prevent the latter in fome degree from imbibing the full action of the folution. This renders the texture of the leather lefs equable, makes it harfh and brittle, liable to crack, and of courfe lefs durable.

Sir Humphrey thinks it probable that another fubftance, befides tannin, combines with the fkin, namely, the extract, to which it owes much of its fupplenefs and tenacity—that the leather gets more of this fubftance from weak infufions of bark, than from the ftrong ones recommended by Seguin —that it is equally infoluble in water—and that, upon the whole, the methods now generally in ufe, may, with a few alterations, be confidered the beft.

The various difcoveries pretended to have been made, and the numerous patents obtained for their ufe and application, have hitherto tended very little to the advancement of fcience or the progrefs of the art. This may fairly be inferred from the conclufion of the celebrated chemift above-mentioned. Indeed it appears by the fpecifications annexed to the patents, that moft of thefe projected improvements purport to be either for the different conftruction and arrangement of the various pits—for the application of mechanical apparatus to diminifh labour—or for extracting the tannin and warming the infufion by artificial heat, with a view to accelerate the procefs. Thefe fancied improvements are only the idle theories and vifionary projects of fpeculative minds: but as it may afford information to the curious, and furnifh hints for future difcovery, we fubjoin

A Lift of Patents for Tanning.

1790. Anthony Fay, efq. of London, for a mechanical apparatus to diminifh the labour of *handling*, to grind the bark very fmall, and to concentrate it, by boiling, into a ftrong extract.

1794. Samuel Afhton of Sheffield, for tanning hides and fkins with certain mineral productions. As fuch materials were prohibited by the ftatute of James I. an act of parliament was paffed to legalize the ufe of them.

1795. Mr. Tucker of Wickham, Hants, for triple pits compofed of wood, metal, and bricks, to keep up a conftant fire at the bottom, to warm the infufion and expedite the procefs.

1796. William Defmond, efq. of London, for a new mode of tanning, according to M. Seguin's method, as before ftated.

1797. Robert Crofs of Lancafter, for pits on a new conftruction, to enable him to apply artificial heat and to tan quickly.

1799. Francis Brewin, efq. of London, for a peculiar conftruction and arrangement of pits, and for the ufe of machinery, &c.

1802. John Lawrence, for the ufe of oak faw-duft in tanning.

1802. Thomas Martin of London, for conftructing pits on a new plan, &c.

1802. John Cant and John Miller of Montrofe, for boiling the bark, &c. fo as to extract the tanning principle more effectually.

1807. Robert John Stanley of Lincolnfhire, for tanning light leather without bark, for a peculiar preparation previous to the application of ooze, and for boiling the materials of tanning.

1813. Sparks Moline, for the ufe of the folid extract of bark.

1815. Thomas Afhmore, efq. for the ufe of all kinds of foot, whether from coal, wood, peat, or bones, and the oils and empyreumatic liquors arifing from them by diftillation or combuftion, to be applied to the purpofes of tanning.

Of the utility of the laft-named patent, we fhall give no opinion at prefent; but of the remainder it may be affirmed that none of the methods therein recommended have ever been much practifed: fome of them which were adopted by a few individuals, were attended with confiderable lofs; and as moft of them are now laid afide, we may reafonably conclude that they have not proved beneficial to the projectors or to the public.

Before we defcribe the prefent method, it may be neceffary to premife, that in different parts of the kingdom, the fame terms and denominations are fometimes employed to defignate diftinct kinds of leather: but all tanned leather is technically claffed and univerfally known under two general denominations; namely, *hides* and *fkins*. The former term being commonly applied to the larger animals, as bulls, oxen, cows, &c. which are chiefly intended for the foles of ftout fhoes, and other purpofes requiring very thick and folid leather; while the latter term is ufed for calves, feals, &c. which, being thinner and more flexible, are intended for the upper leathers of fhoes and boots, for faddles, harnefs, &c.

The heavieft and ftouteft of the bull and ox hides are generally felected to make what are technically called *butts* or *backs*, and are manufactured in the following manner.

When the horns, &c. have been removed, the raw hides are laid on a heap for two or three days, and are then fufpended on poles in a clofe room, called a fmoke-houfe, which is heated fomewhat above the common temperature by a fmouldering fire: this occafions incipient putrefaction,

which loosens the epidermis, and renders the hair and other extraneous matter easy of separation from the true skin. This is effected by extending the hide on a wooden horse or beam of a convex form, and scraping it with a large two-handled knife, called a *fleshing-knife*, which is bent, to suit the convexity of the beam.

The hides are then immersed in a pit containing water slightly impregnated with sulphuric acid. This operation, which is called *raising*, by distending the pores and swelling the fibres, prepares the hide for the reception of the tannin, and renders it more susceptible of its action.

When the hides are sufficiently *raised*, they are removed into a pit, in which they are lain smooth with a stratum of oak bark ground to a coarse powder between each.

The pit is then filled with the tanning lixivium or ooze, prepared from oak bark and water, and the hides remain a month or six weeks without being moved. At the end of this time, the tanning principle being exhausted, the ooze and spent bark are taken out of the pit, and the hides put in again, stratified with fresh bark, and covered with fresh ooze as before. Here they remain about three months, when the same process is repeated, at about the same intervals, three several times or more, according to the strength of the lixivium and the substance of the hides. When sufficiently tanned, they are taken out of the pit, hung up in a shed to dry gradually, and being compressed with a steel instrument, and beaten smooth to render them firm and dense, the operation is complete; and having been numbered, weighed, and stamped by the excise officer, to ascertain the amount, and denote the payment of the duty (which will be noticed at the end of this article), they are ready for sale, and are termed *butts* or *backs*. These form the thickest and most substantial sole leather for very strong shoes, and are chiefly intended for exportation.

Crop hides are thus manufactured. The horns having been removed, the hides are immersed in pits containing a mixture of lime and water, where they remain three or four days, being occasionally moved up and down, that each part may be uniformly exposed to the action of the lime-water. They are then taken out of the lime-pits, and the hair and other extraneous matter being scraped off on a wooden beam, as before described, are washed in water, to free them from the lime and filth adhering. They are now immersed in a weak ooze, and by degrees are removed into other pits, containing solutions gradually increasing in strength, during which time they are taken up and put down (technically termed *handling*) at least once in every day, that all parts of the hide may be acted upon by the tanning principle equally and uniformly. This is continued for about a month or six weeks, when they are put into other pits with stronger ooze and a small portion of ground bark; from whence, as the tannin becomes exhausted, they are removed to other pits in regular succession, with fresh ooze and fresh bark, for two or three months.

At the end of this period, the hides are put into larger vats, called *layers*, in which they are stratified, or lain smooth, in a lixivium of greater strength, and with a larger quantity of ground bark between each fold. Here they remain about six weeks, when they are taken up and relaid in the same manner, with fresh bark and strong ooze, for two months. This process is repeated, with little variation, once, twice, or thrice, at the discretion of the manufacturer, till the hides are thoroughly tanned; when they are taken out of the pits, suspended on poles to dry, and being compressed and smoothed, nearly in the manner before described, are called *crop hides*, and form the principal part of the sole leather which is used in England.

The process of tanning *skins* (calves, seals, &c.) is somewhat different from *hides*. They are continued in the lime-pits for ten or fifteen days; they are then depilated and washed in water, after which they are immersed in an infusion of pigeon's dung, called a *grainer*, having the property of an alkali. Here they remain for a week or ten days, according to the state of the atmosphere and other circumstances, during which time they are frequently *handled*, and scraped on both sides upon a convex wooden beam. This scraping, or *working*, as it is termed, with the action of the *grainer*, helps to discharge all the lime, oil, and saponaceous matter, and renders the skin soft and pliant, fitted to imbibe the tanning principle. They are now removed into pits containing a weak solution of bark, where they undergo nearly the same process of handling, &c. as *crop hides*; but they are seldom stratified in *layers*; and the time occupied in tanning them is usually from two to four months, according to their nature and substance. The skins are then dried, and sold to the currier, who dresses and blacks them for the upper leathers of boots and shoes, for harness, and various other purposes.

The light and thin sort of cow-hides and horse-hides undergo nearly the same process in tanning as calf-skins, and are applied to similar uses.

These processes are such as are now commonly practised, varying, however, with the nature and condition of the peculiar kind of hides and skins—with local habits and circumstances—and with the skill and experience of the manufacturer. The greatest defect in the common methods appears to exist in the means of extracting the tannin from the bark. Cold water is chiefly used for that purpose; but some persons conceiving that this does not entirely exhaust the tanning principle, subject the bark, as before observed, to the action of boiling water, &c. If, however, as sir Humphrey Davy has stated, the extract as well as the tannin combines with the skin, the extraction of the tannin by heat would tend to oxygenate the former, and render it insoluble in the liquid.

The late ingenious Dr. Macbride of Dublin invented and published in 1778 a new method of tanning, the leading feature of which was the use of lime-water, which he conceived would extract the virtues of oak bark more completely than plain water.

It has, however, been observed, that both natural and artificial tannin form compounds with the alkalies and the alkaline earths, and these compounds are not decomposable by skin. Lime forms with tannin a compound not soluble in water, and therefore Dr. Macbride's system is founded on erroneous principles, as so much of the tannin as combined with the lime contained in the water was lost. It was also found, by the practical experience of tanners, that this method was in all respects injurious rather than beneficial; and as it has long been universally rejected, it is not necessary to enter into the detail. The reader who is desirous of further information on this point, may refer to Phil. Transf. vol. lxviii. part i. art. 8.

The application of some new and cheap substitute for oak bark has been long a desideratum in tanning. Catechu, the substance we have spoken of under the article TANNIN, has been recommended, and its powerful tanning properties have been fully ascertained by experiment and actual practice: but it is not likely that the article can be procured in sufficient quantity, or at an adequate price, for the purposes of manufacture. The bark of elm, willow, larch, and other trees, together with *vallonia* (the acorn of a peculiar species of oak in Turkey), have all been employed in tanning with considerable effect.

The greatest hope which chemical science presents, is the

probability that the tanning principle will, at some future period, be formed artificially in such quantities and at such expense as will admit of its general application to practical purposes. The important discovery of Mr. Hatchett already goes far towards the accomplishment of this object. He has distinctly ascertained that a substance very analogous to tannin may be produced by exposing carbonaceous matter, whether vegetable, animal, or mineral, to the action of nitric acid; and has actually converted skin into leather by deal saw-dust, asphaltum, pit-coal, wax-candle, and even by a part of the same sort of skin itself. The changes produced in these bodies, by disuniting and recombining their elementary principles, may by further developement lead to a more economical process of tanning, and thus render essential service to the arts and manufactures.

Tanned leather is subject to a very heavy excise duty. In the ninth year of queen Anne, a duty of 1*d. per* lb. was laid on all hides and skins tanned in Great Britain. In the following year an additional ½*d. per* lb. was imposed. Thus it remained, amidst all the financial difficulties of successive system. But if a different mode of taxation and collection (as in Ireland, on the admeasurement of the pits; or on the raw material, or any other plan) could be adopted, the benefits which would result, both to the manufacturer and to the community, are incalculable. It would leave the tanner at full liberty to conduct his business entirely according to his skill and judgment, and to unite with it the trades of currier and leather-cutter, which are so naturally connected with his own. It would enable him to facilitate the process; to save much superfluous labour; to economize the materials of tanning, which are now unavoidably wasted on useless or inferior leather; to shave, divide, select, and appropriate certain hides and skins, or parts of hides and skins, at the proper time for their peculiar purposes; to prevent the injury which leather often receives in drying at particular seasons; and ultimately to improve the quality and reduce the price of one of the most useful articles of general consumption.

These are matters well worthy the consideration of the executive government and the legislature. Some attention has already been given to this subject by the house of commons in the sessions of 1815 and 1816, and we have no doubt that by further investigation, intelligent and unprejudiced persons might easily arrange and complete a plan which would afford perfect security to the revenue, would simplify the collection, would prevent the possibility of fraud, and at the same time prove extremely beneficial to the manufacture and to the public.

chancellors of the exchequer, till 1812, when, by the act 52 Geo. III. c. 94. a further duty of 1½*d. per* lb. was added, making the whole duty on tanned hides and skins 3*d. per* lb. The annual revenue arising therefrom now amounts to upwards of 500,000*l*.

It may not be improper here to remark, that the excise duty on leather tanned in Ireland, is levied and collected in a different manner.

The act 40 Geo. III. c. 9. passed in Ireland in 1800, instead of imposing a certain duty *per* pound weight, as in England, on all hides and skins tanned with oak bark, imposes a duty of nine pence by the year, for every cubic foot contained in all the pits in the yard of the tanner, allowing a deduction of two-ninths for certain pits called *latches*, which are used solely for the purpose of preparing the lixivium or ooze. By this act the tanner was permitted, on giving certain notice, to discontinue not less than one-fourth, and by 43 Geo. III. c. 97. not less than one-eighth for six months, receiving a proportionate deduction from his monthly payments of the duty. By the 48 Geo. III. c. 62. those acts were made perpetual.

Previous to the passing the Irish act 40 Geo. III. the writer of this article was consulted by the then chancellor of the exchequer in Ireland, on the relative amount of the intended duty of nine pence *per* cubic foot; and upon accurate calculation it was found to bear a fair proportion to the duty then existing in England. If the present duty on leather tanned in this part of the united kingdom were proportionably commuted on a similar plan, it would materially tend to the progress of the manufacture.

The chief obstacle to great practical improvement is the excise duty—not so much from its amount (though that is very considerable), as from the mode in which it is now levied and ascertained, namely, by weight, when the leather is dry and fit for sale. This mode necessarily requires a system of rules and regulations, which, from their multiplicity and complicated nature, subject the manufacturer to daily inconvenience, and to occasional hardships. For, notwithstanding the repeal of the oppressive act 1 James I. cap. 22, and other subsequent statutes, the tanner is still restricted, by various excise laws, from advantageously shaving and reducing his hides and skins—from mixing and removing them at his discretion—and also from exercising the trades of a currier, &c.

Those restrictions, it must be acknowledged, are in some degree necessary for the protection and security of the revenue, while the duties are imposed and collected upon the present

Tar

TAR. See PAMLICO.

TAR, or *Tarr*, a thick dark-brown or black refinous adhefive juice, iffuing from the wood and bark of old pines or firs, either naturally, or by burning. See PINUS.

Some modern writers inform us, that tar flows from the trunks of pines and firs, when they are very old, through incifions made in the bark near the root; that pitch is only tar infpiffated; and both are the oil of the tree grown thick and black with age and the fun. The trees, like old men, being unable to perfpire, and the fecretory ducts obftructed, they are, as one may fay, choaked and ftuffed with their own juice. But the method ufed by our colonies in America of making tar and pitch, is, in effect, the fame with that of the ancient Macedonians; as appears from the account given in the Philofophical Tranfactions. And the relation of Leo Africanus, who defcribes, as an eye-witnefs, making of tar on mount Atlas, agrees in fubftance with the methods ufed by the Macedonians of old, and the people of New England of this day. The greater part of the tar imported into Britain is brought from the Baltic, and is ftill prepared in nearly the fame method which is defcribed by Diofcorides as having been practifed by the ancients. The branches of the trees are cut into billets, and piled up in large ftacks, which are covered with turf. Fire is then applied to the wood, and it is fuffered to burn with a flow fmothered flame, during which procefs the tar is formed by the decompofition of the refinous juice, which flows to the bottom, and runs out through a fmall channel cut for the purpofe. The ftacks are generally built on the flope of a hill, fo that the tar is eafily collected, and put into barrels; in which ftate it is brought into this country. The procefs now defcribed is termed "diftillatio per defcenfum." See PINE.

A more expeditious and economical method of obtaining tar is practifed in France and Switzerland. The wood is heated in large brick ovens, conftructed for the purpofe, and thus it is charred more equally, and the tar is of a more uniform and better quality. In the Vallais the pines are felled in the preceding year, that the wood may be fufficiently dry, and when the outer bark and twigs are ftripped off, the remainder of the tree is cut into billets of tolerably equal fize. The oven is conftructed of ftone or brick, of the fhape of an egg placed on its fmall end: the floor is made either of a flat ftone, fcooped out into a hollow, or of feveral ftones accurately joined together. On one fide of it, about five inches above the loweft part, is a hole, in which a gun-barrel is thruft, and this ferves to convey off the liquid tar that is collected. A large iron grate is laid at the bottom of the oven. The largeft of thefe ovens are about ten feet high, and five or fix feet in the largeft diameter. In charging the oven, bundles of billets are thrown in and fpread as evenly as poffible, the interftices being filled with chips, till the charge nearly reaches the top. The whole is then covered with a layer of chips, and the top of the furnace is clofed with flat ftones heaped upon one another, gradually leffening the opening, and forming a kind of vaulted chimney, the mouth of which is four or five inches acrofs. The dry chips at the top of the furnace are then fet on fire, and the heat fpreads downwards, till the whole charge is fufficiently kindled. The chimney is then entirely clofed with a large ftone, and wet earth is heaped on the ftones at top, and thrown on wherever the fmoke is obferved to burft out too ftrongly. The melting then begins, and the tar falls to the bottom, fills the hollow of the floor (which detains any bits of wood and other impurities), and runs off through the gun-barrel into cafks placed for receiving it. The fire muft be occafionally refrefhed by letting in a fmall draught of air through fmall holes left for the purpofe in the fides of the kiln. When the procefs is finifhed, the wood, completely charred, is taken out, and the oven, after having been cleared out, is again filled. The red wood and knots, being the richeft in refin, are found to yield about one-fourth of their weight of tar; but the general average product is about 10 or 12 *per cent.* of the weight of the whole charge. After each procefs, a quantity of "lamp-black" is collected beneath the ftones that form the vault of the temporary chimney.

According to Theophraftus, not only the turpentine-trees, the pines, and the firs yield refin or tar, but alfo the cedars and palm-trees; and the words *pix* and *rofin* are taken by Pliny in fo large a fenfe, as to include the weepings of the lentifcus and cyprefs, and the balms of Arabia and Judæa; all which perhaps are near of kin, and in their moft ufeful qualities concur with common tar, efpecially the Norwegian, which is the moft liquid and beft for medicinal ufes. Thofe trees that grow on mountains, expofed to the fun or north wind, are reckoned to produce the beft and pureft tar; and the Idæan pines were diftinguifhed from thofe growing on the plain as yielding a thinner, fweeter, and better fcented tar. Every part of the tree, which is at all refinous, is fit for yielding tar; but the red wood and the hard roots yield the beft in quality as well as the greateft in quantity.

Every kind of wood will produce the *pyroligneous* acid (which fee), and tar by the deftructive diftillation. Peat alfo will yield it in abundance.

There is also a kind of tar, the project of making which was suggested by Becher, the celebrated chemist, in the time of king Charles II., which has for several years been prepared from coal in the bishopric of Liege, and in other parts of Germany: we also make considerable quantities in England, especially near Broseley, in Shropshire, and at Bristol. In the bishopric of Liege the coal is distilled in a kind of still, composed of two large cast-iron pots. In England the coal is put into ovens, which are heated by fires lighted under their bottom, and the liquid matter is forced through an iron pipe inserted into the top of the oven, and which communicates with proper condensing vessels. Watson's Chem. Ess. vol. ii. p. 346, &c.

The earl of Dundonald, in Scotland, has lately invented the art of extracting tar and pitch from pit-coal, by a new process of distillation. See Address and Proposals by sir John Dalrymple, 1784.

A substance resembling tar, called "brai-gras," and much used by the French for careening ships, is made in the following manner. The oven, described in the preceding part of this article, is charged with alternate layers of chips of green wood, and billets of dry, and all the refuse matter of turpentine, &c. Over the whole is laid a stratum of "braihee," or rosin, and the gun-barrel pipe is stopped up, and not tapped till the whole of the wood is reduced to charcoal. The vault of the oven is also covered more carefully after the charge is sufficiently kindled, and the whole process is carried on more slowly, and the heat of the fire melts the rosin at the top, which mixes with the resinous sap, and the whole concretes into a dark resinous liquid at the bottom. When it is sufficiently cooled, it is drawn off and barrelled. This "brai-gras" is of an intermediate consistence between tar and rosin. Aikin's Dict.

Tar is properly an empyreumatic oil of turpentine, and has been much used as a medicine both internally and externally.

Tar in substance, mixed with honey, has been found an excellent medicine for coughs.

The ancients esteemed tar good against poisons, ulcers, the bites of venomous creatures; also for phthisical, scrofulous, paralytic, and asthmatic persons. But the method of rendering it an inoffensive medicine, and agreeable to the stomach, by extracting its virtues in cold water, was unknown to them. Siris, sect. 9. 16, 17. 21. 28. See TAR-*water*, infra.

Tar is sometimes given in substance, mixed with so much powdered liquorice, or other such powdery matter, as is sufficient to render it of a fit consistence to be formed into pills. An ointment of tar has been directed in the pharmacopeias, which has been chiefly employed in cutaneous disorders. See UNGUENTUM *è Pice*.

Dr. Cullen mentions an empirical practice, with respect to tar, which is as follows. A leg of mutton is laid to roast, and whilst it is roasting it is basted with tar. Whilst the roasting is continued, a sharp skewer is frequently thrust into the substance of the mutton, so that the gravy may run out: with a mixture of the tar and gravy found in the dripping-pan, the body is to be anointed for three or four nights successively, and during the time the same linen is to be worn. This is alleged to be a remedy in several cases of lepra; and Dr. Cullen knew one instance of its having been employed in a lepra icthyosis with great success; but he had no opportunities of repeating the practice.

But the chief use of tar is for paying the sides of ships and boats, and their rigging, in order to preserve them from the effects of the weather, which would otherwise crack or rot them.

The tar obtained from the deposition of pyrolig----- acid has been recommended as the best preservative for every kind of wood-fence. For this purpose, it should be gently heated in an iron pot, and laid on with a brush. It soaks into the wood, and seems to leave no body, as the artists express it; but after some days' exposure to the sun, the surface and texture of the wood will be much altered; for it will be found so impervious and hard, that it will be very difficult to make any impression upon it. If a second, and especially if a third coat of this tar be put upon wood, it will then *bear out*, as the painters call it, sufficiently well; and Mr. Parkes is of opinion that it will preserve all outside wood-work much more effectually than any other means that have hitherto been employed for the purpose. For ornamental paling, and all outside work, a first, and perhaps a first and second coat of this tar might be used with great advantage; and when these are dry, white lead and oil might be used to finish the work. This substance not only hardens the wood, but effectually preserves it from worms and from all other insects. It will stop the progress of decay, when wood has become worm-eaten. It is observed, however, that this tar is very different from that which is distilled from mineral coal, but which the earl of Dundonald recommended for a similar purpose. The appearance of the application may be very considerably improved by the following preparations; *viz.* 1 gallon of tar, 1 oz. of tallow, 2 oz. of pulverized rosin, melted together and put on warm; — or, 1 gallon of the tar and 2 oz. of pulverized sulphate of iron, used as the other. This tar has also been found an useful varnish for articles made of rolled iron, or of cast-iron. A beautiful varnish for these purposes may be formed by intimately mixing in a gentle heat one gallon of the wood-tar with half a pint of rectified spirits of wine. If this be laid on hot and properly hardened, it will prove a beautiful and durable black varnish. Parkes's Chem. Ess. vol. ii.

Tar may sometimes be found useful as an application for cuts in sheep by clipping, and also to the parts affected by the fly; as well as in those of many other sorts of animals. It is likewise applied to the axles of wheel-carriages, in order to prevent friction, and might probably be still more beneficially made use of in this intention, by having a portion of black-lead incorporated with it, as it would last longer, and be, at the same time, more powerful in obviating the effects of friction.

It is a material which has also been recommended for being applied to the parts of trees from which boughs are taken; in which cases, the faces of the wounded parts and the edges of the bark are to be made perfectly smooth by means of a proper knife; and in a few hours afterwards, or as soon as the parts are become quite dry, they are to be carefully plaistered over with the tar, which is similar to that employed for smearing of sheep; or they may be laid over with white or blue lead paint, well mixed with oil, and made rather thicker than that commonly used in painting. The tar is, however, certainly preferable, being of a more adhering, healing nature; and, when laid on in a thin state, is not so apt to fall off in a scaly manner by the action and effects of the weather, as is the case with the other substances.

As the component parts of vegetable tar have been found to consist of oil, resinous matter, pyroligneous acid, and water; that which is of the finest brown colour, has the least acridity, and which is the freest from a dark black appearance, is probably the best and most proper for use in applications as dressings to animals; though the other kinds may be equally or more beneficial in different other intentions.

Tar, when in intimate mixture and union with butter or lard, and the different precipitates of mercury or sulphur,

forms an excellent application in different diseases of various kinds of animals, especially those of the skin.

TAR, *Barbadoes*. See BITUMEN, and PETROLEUM *Barbadense*.

TAR, *Mineral*. See BITUMEN.

TAR-*Water*. As the cold infusion of tar has been formerly much in vogue, and has been recommended by one of the most learned and ingenious writers of the age, it may not be improper to give some account of its virtues from the bishop of Cloyne's Siris, or chain of reflections concerning the virtues of tar-water.

In some parts of America, tar-water is made by putting a quart of cold water to a quart of tar, and stirring them well together in a vessel, which is left standing till the tar sinks to the bottom. A glass of clear water being poured off for a draught, is replaced by the same quantity of fresh water, the vessel being shaken, and left to stand as before. And this is repeated for every glass, so long as the tar continues to impregnate the water sufficiently, which will appear by the smell and taste.

But as this method produces tar-water of different degrees of strength, the author says he chuses to make it in the following manner: Pour a gallon of cold water on a quart of tar, and stir and mix them thoroughly with a ladle or flat stick, for the space of three or four minutes; after which the vessel must stand eight-and-forty hours, that the tar may have time to subside; when the clear water is to be poured off, and kept for use, no more being made from the same tar, which may still serve for common purposes.

This cold infusion of tar hath been used in some of our colonies as a preservative or preparative against the small-pox, which foreign practice induced the bishop to try it in his own neighbourhood, when the small-pox raged with great violence. He says the trial fully answered his expectation; all those within his knowledge, who took the tar-water, having either escaped that distemper, or had it very favourably. Several were preserved from taking the small-pox by the use of this liquor; others had it in the mildest manner; and others, that they might be able to take the infection, were obliged to intermit drinking tar-water. He says, he has found it may be drank with great safety and success for any length of time, and this not only before, but also during the aforesaid distemper.

The general rule for taking it is, about half a pint night and morning, on an empty stomach, which quantity may be varied according to the case and age of the patient; provided it be always taken on an empty stomach, and about two hours before or after a meal.

It has been found, that several persons infected with cutaneous eruptions and ulcers were immediately relieved, and soon after cured, by the use of this medicine. It is said, that even in the foulest distempers, it proved much more successful than salivations and wood-drinks had done. It also succeeded, beyond expectation, in a tedious and painful ulceration of the bowels, in a consumptive cough, and (as appeared by expectorated pus) an ulcer in the lungs, in a pleurisy and peripneumony. And when a person who had been for some years subject to erysipelatous fevers, perceived the usual forerunning symptoms to come on, the drinking of tar-water prevented the erysipelas.

Tar-water cures indigestion, and gives a good appetite. It is an excellent medicine in an asthma; it imparts a kindly warmth, and quick circulation to the juices, without heating, and is therefore useful, not only as a pectoral and balsamic, but also as a powerful and a safe deobstruent in cachectic and hysteric cases. As it is both healing and diuretic, it is very good for the gravel. The bishop says he believes it to be of great use in a dropsy, having known it cure a very bad anasarca in a person whose thirst, though very extraordinary, was in a short time removed by the drinking of tar-water. From the success of this medicine in five or six instances, the bishop believes it to be the best and safest, either for preventing the gout, or for so strengthening nature against the fit, as to drive it from the vitals.

It may likewise be safely used in inflammatory cases; and, in fact, hath been found an admirable febrifuge, at once the safest cooler and cordial.

The salts and more active spirits of tar are got by infusion in cold water; but the resinous part is not to be dissolved thereby. Hence the prejudice which some, perhaps, may entertain against tar-water, the use of which might inflame the blood by its sulphur and resin, as a medicine, appears not to be well grounded. It is observed by chemists, that all sorts of balsamic wood afford an acid spirit, which is the volatile oily salt of the vegetable. Herein is chiefly contained their medicinal virtues; and this author affirms, that by the trials he has made, it appears that the acid spirit in tar-water possesses the virtues, in an eminent degree, of that of guaiacum, and other medicinal woods.

It is certain tar-water warms, and therefore some may perhaps still think it cannot cool. The more effectually to remove this prejudice, let it be farther considered, that, as on one hand, opposite causes do sometimes produce the same effect; for instance, heat by rarefaction, and cold by condensation, do both increase the air's elasticity; so, on the other hand, the same cause shall sometimes produce opposite effects. Heat, for instance, in one degree thins, in another coagulates, the blood. It is not therefore strange, that tar-water should warm one habit and cool another; have one good effect on a cold constitution, and another good effect on an inflamed one; nor, if this be so, that it should cure opposite disorders.

A medicine of so great virtue in so many different disorders, and especially in that grand enemy the fever, must needs be a benefit to mankind in general. There are nevertheless three sorts of people to whom the bishop says he would peculiarly recommend it; sea-faring persons, ladies, and men of studious and sedentary lives. See Two Letters from the Bishop of Cloyne, &c. published in 1747.

If it be asked, what precise quantity, or degree of strength, is required in tar-water? It is answered, that the palate, the stomach, the particular case and constitution of the patient, the very season of the year, will dispose and require him to drink more or less in quantity, stronger or weaker in degree. Precisely to measure its strength by a scrupulous exactness, is by no means necessary.

It is to be observed, that tar-water should not be made in unglazed earthen vessels, these being apt to communicate a nauseous sweetness to the water.

The same ingenious author recommends tar-water in the plague, and for the distemper among the horned cattle; with what success, must be left to experience.

Though this medicine, says Dr. Lewis, is undoubtedly very far inferior to the character that hath been given of it, it is apparently capable of answering important purposes, as a deobstruent balsamic solution, moderately warm and stimulating. It sensibly raises the pulse, and increases either perspiration or the grosser evacuations. He adds, "I have been informed of some late instances of its good effects in disorders of the leprous kind." Mat. Med.

Dr. Cullen thinks that the acid principle gives the virtue to tar-water, and on this account the bishop of Cloyne properly preferred the Norway tar to that of New England, as the former contains more acid than the latter. This eminent

phyſician acknowledges that he found this preparation in ſeveral caſes to be a valuable medicine; and that it appeared to ſtrengthen the tone of the ſtomach, to excite appetite, to promote digeſtion, and to cure all ſymptoms of dyſpepſia. At the ſame time, it manifeſtly promotes the excretions, particularly that of urine. From all theſe operations, it will be obvious, as the doctor thinks, that in many diſorders of the ſyſtem this medicine may be highly uſeful. Lewis. Woodville.

It has been lately obſerved by Dr. Darwin, that the watering of ground with tar-water is capable of deſtroying the white ſlug, which is ſo highly deſtructive to vegetables.

TAR-*Kettle*, in *Rope-Making*, is made of copper, and holds from ten to twenty barrels of tar. It is ſet in ſtrong brick-work, and over it is faſtened, from ſide to ſide, in the direction of the nipper, a bridge, made of three-inch oak-plank, thirteen inches broad, through the middle of which is a mortiſe for the ſtep to go through, to keep the yarn down and clear of the bottom, when drawing through the kettle. On the ſide of the kettle next the capſtern, is an upright poſt, twelve inches ſquare, in which is fixed a nipper to preſs the tar out of the yarn; and a ſtaff, with a weight ſuſpended at the end, is fixed on the ſide of the nipper to keep it down, that the yarn may imbibe no more tar than is neceſſary.

TAR-*Rope*, a term uſed to ſignify tarred rope, or rope-yarn, ſuch as the thread of old cables, &c. This ſort of tar-rope is uſeful for a great number of different purpoſes, ſuch as thoſe of tying up the wads or ſheaves of beans in the field, and many other ſimilar articles; the faſtening of plants and trees to various kinds of ſupports; and for being applied to a variety of other little uſes of the more domeſtic kind, as being cheap and readily procured.

Teasel

TEASEL, or TEAZEL, in *Botany*. See DIPSACUS.

Beside the common wild species of this plant, there is a large kind of it, the heads of which are of singular use in raising the nap upon woollen cloth, for which it is propagated in great quantities in many parts of the west of England.

The soils most adapted to the growth of this plant are those of the more strong and deep kinds, but which are not too rich; as loamy clays, and such as have strong marly bottoms, and are fit for the growth of wheat crops.

The most favourable situations are those that are rather elevated, open, and incline a little to the south; and the higher grounds, particularly where the country is inclosed, are the most advantageous.

For the preparation of the ground, where it is a lea, it should be ploughed up deeply in the early part of the year, as in the beginning of February; and where it is inclined to moisture, it should be executed in narrow ridges of not more than three bouts each, the furrow slices being laid over in as even and regular a manner as possible, the fine mould from the furrows being raised by the plough or spade so as to cover the surface. But in lands that are sufficiently dry, and which are broken up from stubble, the ploughing may be deferred to a later period, and be laid in ridges of much greater breadths, and in a more flat form.

Mr. Billingsley, in his Agricultural Report of Somersetshire, has remarked, that in the providing seed, it should constantly be taken from such plants as are the most perfect of their kind, and the most productive in heads; as there is much difference in the quantity that is afforded by different plants, some producing nearly a hundred, while others do not afford more than three or four. It should be suffered to remain till it becomes perfectly ripened, and be used while fresh.

With respect to the proportion of seed, that which is mostly employed on the acre is from about one to two packs, according to the above writer; but some make use of a larger quantity, as two pecks, or more.

It may be noticed, in regard to the season of putting in crops of this sort, that it is commonly about the middle of March or beginning of April. The common method of putting this sort of crop into the ground is the broad-cast, it being sown evenly over the surface, in the manner that is practised for turnips, sown in this way. But before this is done, the land should be well harrowed down, in order to afford a fine state of mould as a bed for the seed. It is then to be covered in by a slight harrowing with a light short-tined harrow, such as is used for grass-seeds. Some, however, prefer a light bush-harrow for this purpose.

However, this sort of crop may be sown in rows in the drill method, at the distance of eight, twelve, or more inches from each other, in the same way as that of the drilled turnip. But this method is not, we believe, yet much employed by those who are in the practice of raising crops of this nature.

In the after-culture of crops of this kind, much depends on the land between the plants being kept perfectly clean and free from weeds; in having them set out to proper and sufficient distances, as about twelve inches; and in having them well earthed up. Some cultivators perform frequent diggings, that the ground may be rendered cleaner and more mellow, consequently the growth of the plants be the more effectually promoted. This business has usually the name of spaddling, or spittling, and is executed with great dispatch by labourers that are accustomed to perform it. When these diggings have been finished, nothing further is necessary till the period of cutting, which is generally about the end of the month of July in the second year, which is known by some of the uppermost heads beginning to blow; as when the blossoms fall, they are ripe, and in a state to be cut and secured.

This cutting is mostly executed at three different times, at the distances of about ten days or a fortnight from each other. It is performed by means of a knife, contrived for the purpose, with a short blade, and a string attached to the haft. This last is done, in order that it may be hung over the hand or wrist, when the leaves are to be stripped from the stem parts. A pair of strong gloves is likewise necessary. Thus prepared, the labourer cuts off the ripe heads along the rows or lines, or otherwise, with about nine inches of stem, and ties them up in handfuls with the stem of one that is more perfectly ripened, or otherwise. And on the evening of the day on which they are cut, they should be put into a dry shed; and when the weather is fine, and the air clear, they should be taken out and exposed to the sun daily, till they become perfectly dry. As soon as they are completely dried, they should be laid up in a dry room, in a close manner, till they become tough and of a bright colour, and ready for use. They should then be sorted or separated into three different kinds, by opening each of the small bundles. These are distinguished into *kings*, *middlings*, and *scrubs*, according to their different qualities. They are afterwards, the author of the above report says, made into packs, which, of the first sort, contain nine thousand heads; but when of the second, twenty thousand; the third is a sort of very inferior value. By some, before forming them into packs, they are done up into what are termed staves, by means of split sticks, when they are ready for sale.

The produce in crops of this nature must be very uncertain, there being sometimes fifteen, or sixteen, or more packs on the acre; and at other times scarcely any. The produce is disposed of to the cloth manufacturers in Somersetshire, Wiltshire, and Yorkshire.

It has been stated, that formerly an acre of land, if well grown, and what is deemed a full crop, often produced nine packs of *kings*, nineteen of *middlings*, and two of *scrubs*.

In the county of Essex, they have a singular practice of cultivating and growing teasel crops with seeds, such as coriander and carraway, producing thereby a sort of treble crop. It is stated, that the seeds of these several plants are sown together, very early in the spring, upon a strong old lay, once ploughed; and generally yield very considerable returns.

It is noticed, that the head of the teasel is of a conical form, two or three inches in length, and one or one and a half in diameter at the bottom, or largest end; armed on every part with small strong points, turned a little downwards; and are bought by the woollen manufacturers, who fix them upon frames, calculated to cover a cylinder, which is made to turn round, and slightly catch their says, bays, and other such articles, which another part of the weaver's machine draws against them; by which means the knap is raised to almost any length the manufacturer wishes.

The largest burs, and those most pointed, are esteemed

the beat, and are now called *male* teafels; they are moftly ufed in the dreffing and preparing of ftockings and coverlets; the fmaller kind, properly called the *fullers'* or *drapers'* teafels, and fometimes the *female* teafel, are ufed in the preparation of the finer ftuffs, as cloths, rateens, &c. The fmaller kind fometimes, called *linnots heads*, are ufed to draw out the knap from the coarfer ftuffs, as bays, &c.

The leaves of the common wild teafel dried, and given in powder or infufion, have been commended by fome as a powerful remedy againft flatufes or crudities in the ftomach.

Tempering

TEMPERING, in the *Mechanic Arts*, the preparing of ſteel and iron, ſo as to render them more compact, hard, and firm; or even more ſoft and pliant; according to their reſpective occaſions.

Theſe metals are tempered by plunging them, while red-hot, into ſome liquor prepared for the occaſion: ſometimes pure water is uſed for that purpoſe: our lockſmiths, &c. ſcarçely uſe any other.

When an inſtrument has been properly hardened, it is neceſſary to give it a certain degree of ſoftneſs, in order to adapt it for the purpoſe to which it is to be applied. With this view, it ſhould be heated again to a certain point, uſually determined by its colour, and then inſtantly plunged into cold water. This is called "letting it down to the proper temper." It has been a queſtion of difficult ſolution, how the water acts in hardening iron and ſteel. It is well known, ſays Mr. Parkes, in his "Chemical Eſſays," (vol. iv.), that the hotter any piece of iron is made, and the more quickly it is cooled, the harder it will become in its texture; and he ſuggeſts that this may be owing to the loſs of its *latent* heat. In confirmation of this conjecture he alleges, that iron and ſteel are generally allowed to owe their malleability to their latent heat.

A compoſition of divers juices, liquors, &c. has ſometimes been uſed; which is various according to the opinion and experience of the workman: as vinegar, mouſe-ear water, nettle or Spaniſh radiſh-water, the water oozing from broken glaſſes, ſuet, ſalt, oil, ſoot, diſtilled wine, ſal ammoniac, urine, &c. But theſe methods are now generally abandoned. Mr. Stodart, a very ingenious and ſcientific cutler in London, ſays, (as Mr. Nicholſon informs us, Journal, vol. iv. 4to.) that one of his workmen makes up his charcoal fire with ſhavings of leather, finding that this is effectual in preventing the tools from cracking in the proceſs of hardening; and he ſays, that he has found no advantage from the uſe of ſalt in the water.

To harden and temper Engliſh, Flemiſh, and Swediſh ſteel, you muſt give them a pretty high heat; then ſuddenly quench them in water to make them hard; but Spaniſh and Venetian ſteel will need only a blood-red heat before they be quenched.

In conſequence of this operation, all the qualities of ſteel are changed; ſo that from being very ductile and ſoft, it becomes ſo hard and ſtiff, that it is no longer capable of being cut by the file, but is itſelf capable of cutting or piercing very hard bodies, and that it does not yield to the hammer, but may be ſooner broken in pieces than extended. It becomes alſo ſonorous, brittle, very elaſtic, and capable of acquiring the moſt beautiful poliſh. This hardneſs and ductility of ſteel may be diverſified by varying the temper. The hotter the ſteel is when tempered, and the colder the water into which it is plunged, the greater hardneſs it acquires, but at the ſame time it becomes ſo much more brittle. The coldneſs of the water may be increaſed by diſſolving ſalts in it: obſerving that water is always colder while the ſalts continue diſſolving; and that the ſteel will cool ſooner by being ſtirred about or placed in a ſtream, ſo as to come in contact with water not already made warm. On the contrary, the leſs hot the ſteel is when tempered, and the hotter the water is in which it is tempered, the leſs hard it becomes, and alſo the greater ductility it retains: and the proper degree of heat is always relative to the uſe for which the tools made of the ſteel are intended.

If the ſteel be too hard or brittle for an edged tool, &c. let it down by rubbing a piece of grindſtone or whetſtone hard upon the work, to take off the black ſcurf: then brighten, or heat it in the fire: and as it grows hotter, you will ſee the colour change by degrees, in the manner and by the gradations ſtated under the article CUTLERY.

Saw-makers temper their tools by rubbing them over with ſuet or other greaſe, and then heating them gradually till the temperature of each tool is ſufficiently raiſed to ſet fire to the greaſe of itſelf and occaſion it to blaze. They are thought to acquire in this mode of treatment a temper equal to that which would be obtained by heating them in the uſual way, till they became of a deep blue. This operation, which is practiſed at Sheffield, is called "blazing." For the method of tempering files, in which the great deſideratum is to blend tenacity with hardneſs, ſee FILE.

In the year 1789, Mr. David Hartley took out a patent for a method of tempering ſteel by the aid of a pyrometer or thermometer applied near to the ſurface of the article, and at the ſame time recommended the uſe of heated oil, in which (he ſays) many dozens of razors or other tools might be tempered at once with the utmoſt facility, and the various degrees of heat neceſſary for different purpoſes might ſpeedily be determined by experiment. (See Nicholſon's Journal, vol. i. 4to.) An improvement of this principle has been ſince ſuggeſted by Mr. Parkes (Chem. Eſſ. vol. iv.) by providing a bath of oil or of ſome kind of fuſible metal for the tempering of every ſpecies of edged tool, which contrivance would, in his opinion, give to this operation a greater degree of certainty, than has ever been experienced by thoſe who have conducted ſuch manufactories. See TILTING.

Steel is uſually ſold tempered, becauſe in many manufactures, the cuſtom is to temper it as ſoon as it is made, probably that the purchaſers of it may be better able to judge of its quality. When this ſteel is to be uſed, it muſt be untempered by heating it more or leſs, and letting it

cool ſlowly, that it may be extended, filed, and receive the neceſſary form: after which every workman tempers it again in his own way.

M. Berthoud, in his treatiſe on marine clocks, recommends hardening the ſteel-balance wheel, by daubing it over with ſoot (of wood) moiſtened with urine, putting it into a ſmall box of thin iron-plate, and covering it over with the ſame compoſition. This box with its contents is to be heated to a blood-red, and then the wheel taken out ſuddenly and quenched.

Mr. Harriſon and M. Berthoud ſeem to agree upon the whole, that the balance-ſpring of time-pieces ſhould be hardened and tempered after it has been coiled up in its proper form; and not tempered firſt and coiled up afterwards, as is the practice in making the main-ſpring. Some curious workmen, in order to equally temper ſmall ſteel inſtruments, employ melted lead as an intermedium. A plate of iron floats upon the melted lead, and receives from it, in all its parts, an equal heat: the pieces of ſteel laid upon this plate, acquire all at once the ſame degree of heat, and are at once quenched in water; the blue or other colours, which they ſucceſſively aſſume, affording ſure marks of the proper points of heat at which they are to be quenched, according to the different degrees of hardneſs required in them. Lewis's Com. Phil. Techn. p. 32.

For the method of tempering ſteel bars for artificial magnets, practiſed by Mr. Canton, ſee *Artificial* MAGNET.

The ancients appear to ſome to have had a better method of tempering than any of the moderns are acquainted with; witneſs their works in porphyry; a ſtone ſo hard, that ſcarcely any of our tools make any impreſſion upon it.

TEMPERING *of Land*, in *Agriculture*, a term ſignifying the preparing it for a crop, eſpecially of wheat. It is a term in much uſe in Norfolk. It implies all the various operations that may be undertaken in this intention.

Test and Testing

TEST, in *Metallurgy*, is a veſſel of the nature of a coppel, uſed for large quantities of metals at once, and formed of the ſame materials.

The coppels, or ſmall veſſels, ſerve for operations of this kind, when ſmall quantities only are concerned; but when larger are worked on, veſſels of a larger ſize and coarſer texture are employed, which are diſtinguiſhed by the name of *teſts*.

Theſe are uſually a foot and half broad, and are made of wood-aſhes, not prepared with ſo much care as for coppel-making, and mixed with finely powdered brick-duſt; theſe are made into the proper ſhape, either by means of a ſhallow veſſel, made of crucible earth, or caſt-iron, of proper dimenſions, or only an iron ring, or hoop, with three bars arched downwards acroſs the bottom, about two inches deep, and of different widths, from three or four inches to fifteen or more, according to the quantity of metal to be teſted at once.

To make them in the firſt manner, an earthen veſſel is to be procured, not glazed within, and by its depth and breadth proportioned to the quantity of metal to be worked; the inſide of this veſſel is to be well moiſtened with fair water, that the aſhes to be put into it may adhere the better. Put into this veſſel, thus prepared, the aſhes and brick-duſt before-mentioned, and firſt moiſtened either with water alone, or with water with a little white of an egg mixed in it; let the quantity of this be ſo much as will half fill the veſſel, then preſs the maſs with a wooden indented peſtle, or, if not for a very large teſt, with a wooden cylinder, only of an inch thick: when thus preſſed down add freſh aſhes, and preſs them a ſecond time, as in the making of coppels, and repeat this addition of freſh aſhes till the earthen veſſel be nearly full; then remove the ſuperfluous aſhes with an iron ruler, and let the inequalities remaining at the border be ſmoothed with a wooden or glaſs ball rolled round about. This done, you are to cut the cavity with a bowed iron, that you may have a broad ſpherical ſegment, not very deep; and laſtly, by means of a ſieve, ſtrew this cavity carefully and regularly over with dry aſhes of bones of animals, ground extremely fine, and ſqueeze theſe hard in, by the rotation of the wooden or glaſs ball. Thus you have a teſt finiſhed, which, together with its earthen pot, muſt be ſet in a dry warm place.

To make the teſts in the other manner, or by means of an iron ring; let a ring of that metal be filled with aſhes mixed with brick-duſt, and moiſtened as before mentioned, in ſuch manner that they may riſe conſiderably above the ring; then preſs them ſtrongly either with your hands, or with an indented peſtle, and afterwards, with gentle blows of a rammer, preſs the aſhes from the circumference toward the centre, in a ſpiral line, and that in ſuch manner, that, after having been ſufficiently preſſed, they may be a ſmall matter higher than the brink of the ring. If there are now any vacancies in the maſs, empty the ring, and fill it again with more aſhes; for if you ſhould attempt to fill up theſe by adding, were it but ever ſo little, aſhes, the ſecond, or additional quantities, will never cohere ſo firmly with the firſt, but that they may probably ſeparate in the operation.

This done, turn the ring upſide down, and on the other ſide, or bottom, take out the aſhes to the quantity of one-third part of the depth of the ring, and again fill the vacuity with the ſame aſhes, in ſuch a manner that there may remain no ſenſible cavity,

When the maſs is thus prepared, cut out a cavity in the larger ſurface of the ring, with a bowed iron, as in the former method.

The Germans have, beſide theſe, another kind of teſts, which they call *treibſcherben*. Theſe are a ſort of veſſels which reſiſt the moſt violent fire, and are ſo extremely compact, that they ſometimes will retain not only melted metals, but even the glaſs of lead itſelf.

The figure and ſize of theſe veſſels may be the ſame with that of the coppel, but they are uſually made larger; and the great difference of theſe teſts from coppels, and from the ordinary teſts, which are indeed only a kind of large and coarſe coppels, is, that the matter of theſe is more compact and coherent.

The matter for making theſe teſts is thus prepared: take of the pureſt and fineſt clay a ſufficient quantity, make it into balls, and dry them either in the air, or on the fire; when dried, beat them to powder in a mortar, and pour on the powder a great quantity of warm water; let this mixture reſt a while, and when the clay has ſubſided, pour off

TESTING, in *Metallurgy*, denotes the operation of refining large quantities of gold and ſilver, by means of lead, in the veſſel called a *teſt*. This operation is performed by the deſtruction, vitrification, and ſcorification of all the extraneous and deſtructible metallic ſubſtances with which thoſe noble metals are alloyed. It conſiſts in adding to the alloyed gold and ſilver, a certain quantity of lead, and in expoſing afterwards this maſs to the action of the fire. The lead, by increaſing the proportion of imperfect metals, prevents them from being ſo well covered and protected by the perfect metals; by uniting with theſe, it communicates to them a property it has of loſing very eaſily a great part of its inflammable principle; and laſtly, by its vitrifying and fuſing property, which it exerciſes with all its force upon the calcined and naturally refractory parts of the other metals, it facilitates and accelerates the fuſion, the ſcorification, and ſeparation of theſe metals. The lead, which in this operation is purified, and ſcorifies along with it the imperfect metals, ſeparates from the metallic maſs with which it is then incapable of remaining united: it floats upon the ſurface of the melted maſs; becauſe by loſing part of its phlogiſton, (according to the former language of chemiſts,) it loſes alſo part of its ſpecific gravity, and laſtly it vitrifies. The removal of the vitrified matter in the proceſs is procured either by the nature of the veſſel in which the melted matter is contained, and which, being porous, abſorbs and imbibes the ſcorified matter as faſt as it is formed; or by a channel cut in the edge of the veſſel through which the matter flows out.

The proceſs of teſting is generally performed in the ſame manner as that of cupellation. See Assaying and Copelling.

But when great quantities of baſe metal are to be worked off from a little gold, recourſe is had to a more expeditious method, that of teſting before the bellows. An oval teſt is placed in a cavity, made in a hearth of a convenient height, and ſome moiſtened ſand or aſhes preſſed round it to keep it ſteady: the noſe of a bellows is directed along its ſurface, in ſuch a manner, that if aſhes are ſprinkled in the cavity of the teſt, the bellows may blow them completely out; ſome have an iron plate fixed before the bellows, to direct the blaſt downwards. To keep the ſurface of the teſt from being injured in putting in the metal, ſome cloths or pieces of paper are interpoſed. The fuel conſiſts of billets of barked oak, laid on the ſides of the teſt, with others laid croſs-wiſe on theſe: the bellows impels the flame on the metal, clears the ſurface of aſhes or ſparks of coal, haſtens the ſcorification of the lead, and blows off the ſcoria, as faſt as it is formed, to one end of the teſt, where it runs out through a notch made for that purpoſe. About two-thirds of the ſcorified lead may be thus collected; the reſt being partly abſorbed by the teſt, and partly diſſipated by the action of the bellows. Care muſt be taken not to urge the blaſt too ſtrongly, leſt ſome portion of the gold ſhould be carried away by the fumes impetuouſly forced off from the lead, and ſome minute particles of it entangled and blown off with the ſcoriæ. Macquer's Chem. Dict. Art. *Refining.* Lewis's Ph. Techn. p. 146.

the water which ſwims at top; and let this waſhing be ſo often repeated, that all the moſt minute lumps of the clay be broken, and whatever ſalt it contains perfectly waſhed out: then add to this fine clay, of the pureſt ſand, of powder of calcined flints, ground, and well waſhed, of faulty but clean Heſſian crucibles, or of any incombuſtible ſtones ground very fine, ſuch a quantity as will render the maſs thick, and hardly adhering to the hands in kneading it, or pliant when rolled into a thin lamina.

This is the matter for making this ſort of teſts; but, before any quantity of the veſſels be made of this earth, it will be prudent firſt to finiſh a ſingle one, and try it, by putting on it a quantity of glaſs of lead, and expoſing it for an hour or more to the ſtrongeſt fire; by this trial you will be certain whether or not the maſs is capable of making veſſels that will reſiſt both the fire and the glaſs of lead; and by no other means but this trial is it poſſible to determine the due proportion of the mixture of the ingredients for this uſe, on account of the variety of the clays. Nature in ſome places affords a clay ſo well tempered, that it is extremely proper for the making of teſts without any preparation, or without the admixture of any other matter. Sometimes this only requires a ſimple waſhing, but commonly it is neceſſary to make it into balls, and powder or waſh them as before directed.

On the trial of a teſt made of this, or the former mixed clay, if it runs into glaſs, you muſt add to it of the powder of ſtones, eſpecially ſuch as beſt reſiſts the fire. Great care is to be taken not to add too much powdered chalk to theſe compoſitions, ſince if the matter is tempered with that alone, the teſts will indeed reſiſt the fire very well, but being too porous, they will yield a paſſage to litharge, which will ſoften them to ſuch a degree, that they will either fall aſunder of themſelves, or be totally cruſhed when taken hold of with the tongs.

Theſe veſſels are to be made in the following manner: rub over the ſides and bottom of a ſmall mortar, and alſo its peſtle, with oil, or with the fat of bacon; fill it two-thirds full of prepared clay, then make a ſlight impreſſion with your fingers in the middle of the clay; then place the bottom of the peſtle there, and force it down with blows of a hammer, the ſtronger the better. When thus properly hollowed, take it out of the mortar, and pare its edges, and dry it, as the coppels are dried, in the air, in a dry warm place.

Teſts thus prepared may be uſed as ſoon as dry, unleſs for ſalts or litharge; but theſe bodies, when melted in veſſels not firſt baked or hardened in the fire, always make their way through them.

Some of the German writers alſo recommend, both for teſts and coppels, a ſort of friable opaque ſtone, called white ſpath, which appears to be a ſpecies of gypſum, or of the ſtones from which plaſter of Paris is prepared. The ſpath is directed to be calcined with a gentle fire, in a covered veſſel, till the ſlight crackling, which happens at firſt, has ceaſed, and the ſtone has fallen in part into powder; the whole is then reduced into ſubtle powder, which is paſſed through a fine ſieve, and moiſtened with ſo much of a weak ſolution of green vitriol, as is ſufficient for making it hold together. Gellert, however, finds, that if the ſtone is of the proper kind, which can be known only by trials, calcination is not neceſſary. Theſe teſts are liable to ſoften or fall aſunder in the fire, which inconvenience may be remedied, according to Scheffer, by mixing with the uncalcined ſtones ſomewhat leſs than equal its weight, as eight-ninths of ſuch as had been already uſed and penetrated by the ſcoria of the lead, taking that part of the old teſt which appears of a green-grey colour, and rejecting the red cruſt on the top. But from his account it appears, that theſe teſts are leſs durable than thoſe made of the aſhes of bones, though much ſuperior to thoſe of wood-aſhes. Vegetable aſhes, which ſtand pretty well the teſting of ſilver, can ſcarcely bear any great quantity of gold, which requires a conſiderably ſtronger fire than the other; but bone-aſhes, ſays Dr. Lewis, anſwer ſo effectually, and are among us ſo eaſily procured, that it is unneceſſary for the refiner to ſearch for any other materials. Cramer's Art of Aſſaying, p. 60. 62. Lewis's Com. Ph. Tech. p. 144.

Tilt-hammer

The tilt-hammer is diftinguifhed from the lift-hammer, or forge-hammer, by the manner in which it is lifted up by the cogs of a wheel which is turned by the mill.

The forge-hammer is mounted on a centre of motion at the extremity of the haft or helve of the hammer oppofite to the head of the hammer, and the cogs of the wheel operate beneath the helve near the head, to lift or tofs up the hammer againft a ftrong wooden fpring called the rabbit, which is firmly fixed over the head of the hammer. This fpring reflects the hammer down upon the anvil with greater force and fmartnefs than the hammer would defcend by the action of gravity alone. A lift forge-hammer is defcribed under the article IRON. See *Plate* IV. *Iron Manufacture.*

The tilt-hammer is poifed on pivots or a centre of motion, which is about the middle of the length of the helve, or fometimes at two-thirds from the head. The cogs of the wheel are made to act on the tail of the helve beyond the centre of motion, and they prefs down the end of the tail, and thus caufe a correfpondent elevation of the head of the hammer. Sometimes the fpring is placed over the head of the hammer, the fame as a lift-hammer; but more commonly, the tail of the hammer is made to ftrike againft a fixed floor; and when the head of the hammer is thrown up fuddenly, the momentum given to it caufes the head to rife up after the tail ftrikes the floor, and thus bends the helve, which by its elafticity caufes the head of the hammer to defcend fmartly upon the anvil.

The *tilt-mills* in the neighbourhood of Sheffield are very fimple: they are worked by a fmall water-wheel, upon the axis of which is a wheel with a great number of cogs, fixed in its circumference. Thefe fucceffively deprefs the tail of the hammer, and raife its head: the hammer falls by its own weight, aided by the fpring of the helve, upon the hot metal. The fize of the water-wheel, and the number of cogs in the wheel, are adapted to produce from three hundred to four hundred ftrokes *per* minute.

This great number requires the water-wheel to move with a velocity which is inconfiftent with the beft mode of applying the fall of water, becaufe it is well known that water, as well as any other heavy body, can only defcend with a certain fpeed. If, therefore, the floats of the wheel are required to turn with a great rapidity, it is evident the proportion of work the wheel will perform, will be but fmall in proportion to the quantity of water expended. For this reafon, it is found to be a great improvement in tilt-mills to add cog-wheels which will give the hammers a fufficient velocity, while the water-wheel turns at fuch a rate as is found to produce the greateft power from a given quantity of water.

A capital mill of this kind is delineated in *Plate* VIII. *Iron Manufacture.* It was made at the Carron iron-works in Scotland, after defigns of the celebrated Mr. Smeaton. It is adapted for forging iron into bars, and has three tilt-hammers of different powers for different kinds of work. Thefe hammers are not made to ftrike fo quick as is ufual in the Sheffield mills for the tilting and drawing out fteel bars; but by giving a greater number of cogs to the wheels, the requifite rapidity may be obtained without increafing the fpeed of the water-wheel. A capital mill was built at Sheffield about fix years ago, which is on Mr. Smeaton's plan, except in the proportions of the wheels, and its performance is fuperior to any of the other tilt-mills.

A A, in the plan *fig.* 1. are the walls of the building; B B the great water-wheel, which is of the kind called a breaft-wheel. (See WATER-*Wheel.*) It is 18 feet diameter and 5 feet broad. The total defcent of the water which actuates it is 7 feet 2 inches, and it falls upon the float-boards rather below the centre of the wheel, being retained againft the floats by what is called the breafting, that is, a fweep or curved wall of mafonry, which is accurately adapted to the float-boards of the wheel, and as clofe to them as is poffible, to avoid touching.

The axis C of the water-wheel is carried through the wall A, and on the extreme end of it is a large iron wheel D, of 90 wooden teeth, 9 feet 6 inches diameter. This turns a pinion E of 30 teeth, and 3 feet 2 inches diameter. The pinion is fixed on one end of a caft-iron axis G G, which is made very large, for ftrength, and hollow within, like a pipe. The gudgeons *b* and G are fixed into it at each end, and upon thefe gudgeons it revolves. F F is a caft-iron fly-wheel, fixed on the axis clofe to the pinion; it is 12 feet diameter, and the rim 6 inches by 5. The weight is very confiderable, and gives it a momentum to regulate the motion of the whole mill, and equalize all irregularities which arife from the fucceffive actions of the mill to raife the three hammers, L, M, and N.

Each hammer has a feparate cog-wheel, K, I, and H, to give it motion, which is effected by the cogs of thefe wheels acting upon the tails of the hammers and preffing them down. This is explained by the elevation *fig.* 2. where *e* is the iron head of the hammer, *f* its centre of motion, and *d* the tail or extreme end, upon which the cogs of the wheel act, and which is plated with iron on the upper fide, to prevent it from wearing.

P is the anvil-block, which muft be placed on a very firm foundation, to refift the inceffant fhocks to which it is fubjected: the centre, *f*, or axis of the hammer, is fupported in a caft-iron frame, *g h*, called the hirft. When the cogs of the wheel ftrike the tail of the hammer fuddenly down, and raife the head, the lower fide of the tail of the hammer ftrikes upon a fupport *n*, which acts to ftop the afcent of the head of the hammer *e*, when it arrives at the defired height; but as the hammer is thrown up with a confiderable velocity as well as force, the effort of the head *e* to continue its motion, after the tail ftrikes the ftop *n*, acts to bend the helve L of the hammer, and the elafticity of the helve recoils the hammer down upon the anvil with a redoubled force and velocity to that which it would acquire from the action of gravity alone.

To obtain this action of recoil, the hirft *gh* muft be held down as firmly as poffible; and for this purpofe, four ftrong iron bolts are carried down from the four angles of the bottom plate *h*, and made faft to the folid bafis of ftone R R, upon which the whole refts: upon this bafis are placed four layers of timbers, *i*, *k*, *l*, *m*, which are laid one upon another, and the timbers of each layer are laid crofsways over the others. Each layer confifts of feveral pieces laid fide by fide, and they are flightly treenailed together, to form a platform. Each platform is rather lefs than that upon which it refts, fo as to form a pillar of folid timber; on the top of which the hirft-frame *g h* is placed, and firmly held down by the four bolts, which defcend through all the platforms, and have fecure faftenings in the folid mafonry beneath.

The ftop *n* is fupported by a fimilar pillar, but fmaller, and compofed of three layers: the upper piece *n*, which is feen croffways in *fig.* 2, is about three feet long, and the under fide is hollowed, fo that the piece bears only upon the two ends, leaving a vacancy beneath it, which occafions

it to bend or spring every time the tail *d* of the hammer strikes upon it, and this aids the recoiling action very much.

The axis on which the hammer moves is formed by a ring of cast-iron, through which the helve of the hammer is put, and held fast by wedging round it. The ring has a projecting trunnion on each side, ending in an obtuse conical point, which is received in a socket firmly fixed in the hirst-frame *g h* by screws and wedges, one of which is seen at *r*. These two sockets are thus capable of adjustment, so as to make the hammer face fall flat upon the anvil. The three wheels K, I, H, are of different sizes and numbers of cogs to produce that velocity in each hammer which is best adapted for the work it is to perform: thus, the wheel K for the great hammer has eight cogs, and therefore produces eight blows of the hammer for each revolution of the fly-wheel; the wheel I for the middle hammer has twelve cogs; and the wheel H for the small hammer sixteen; the latter will therefore make two strokes for every one of the great hammer. In fixing the three wheels upon the great shaft G H, care is taken that they shall produce the blows of the different hammers in a regular succession, and equalize as much as possible the force which the water-wheel must exert. The wheels are fixed upon the shaft by means of a wedging of hard wood, driven in all round; the wood, being capable of yielding a little to the shocks occasioned by the cogs meeting the tails of the hammers, renders the concussions less violent.

The following are the principal dimensions:

The head of the great hammer, P, weighs $3\frac{1}{4}$ cwt., and it is intended to make 150 blows *per* minute: it is lifted 17 inches from the anvil at every blow.

The middle hammer, M, is 2 cwt., and makes 225 blows *per* minute: it is lifted 14 inches each time.

The small hammer, N, weighs $1\frac{1}{2}$ cwt., and makes 300 blows *per* minute: it is lifted only 12 inches.

To produce these velocities, the great axis G must make $18\frac{3}{4}$ turns *per* minute; and the cog-wheels E and D, being in the proportion of one to three, the water-wheel must make $6\frac{1}{4}$ revolutions *per* minute; the water-wheel being 18 feet diameter, its circumference will be $18 \times 3.1416 = 56.54$, or $56\frac{1}{2}$ feet: this multiplied by 6.25 is about 353 feet motion *per* minute, or divided by $60 = 5.9$ feet motion *per* second for the circumference of the water-wheel.

The tilt-mills employed in the manufacture of steel, do not have the great hammer P, but the largest they use is about the size of that at M, and is adapted for welding faggots of steel to make shear steel: the other two hammers are about the size of N, and are made to work much quicker, *viz.* from 350 to 400 blows *per* minute. This is very easily accomplished by making the wheels E and F as 1 to 4, instead of 1 to 3, as shewn in the drawing.

TILTH, in *Agriculture*, a term used to signify the condition of the earth or soil after the land has been ploughed and broken down by the harrow or other tool of the same kind; or the state and circumstances of the ground in regard to tillage, or heart, as relating to manure. Thus we have a *good* and *bad* tilth, as well as land *in* and *out* of tilth, in works on agriculture.

TILTIL, in *Geography*, a town of Chili; 30 miles S.E. of Valparayso.

TILTING *of Steel*, the process by which blistered steel, or steel in the raw state, is rendered ductile and fit for the purposes of various manufactures. Tilting consists in hammering or forging the steel by a large hammer called a *tilt*. See TILT-*Hammer*.

Steel is formed by two processes: one in which it is made at once from pig or crude iron in the finery, nearly in the same manner as making bar-iron: this is called natural steel. In the second process, malleable iron, in bars, is imbedded in charcoal or other carbonaceous matter, and exposed to a considerable heat, till the carbon is thought to have penetrated sufficiently into the iron to have changed it into steel. This is called converting the iron by cementation with charcoal; and the furnace in which the operation is performed is called a converting furnace.

The object of this process of cementation, is to impregnate the iron with a certain quantity of carbon, to be derived from the charcoal: like many other simple operations, it requires great care and nicety to perform it properly, when put in practice on a large scale. The iron must be exposed to the action of an intense heat in contact with carbon (but defended from the access of oxygen), until the iron imbibes a portion of carbon and becomes steel.

The quantity of carbon which must be combined with iron to produce steel, admits of considerable latitude, and the qualities of the steel vary in the same proportion: with too little carbon, steel will be soft; and not sufficiently hard when it has been suddenly cooled by plunging in water. It has a rough and somewhat fibrous fracture, and in general may be said to possess many of the qualities of malleable iron. On the other hand, in proportion as the quantity of carbon is diminished, an over-cemented steel, containing an excess of carbon, is brittle, easily fusible, excessively hard after being suddenly cooled, and is liable to crack on the sudden change of temperature from hot to cold. All these properties are an approach to crude iron.

The received opinion respecting steel and the best cast-iron is, that they have the same constituent parts, but in different proportions; the former containing a smaller proportion of carbon than the latter. All the crude or cast-iron of commerce contains oxygen in greater or less proportion, but the best steel is supposed to be nearly free from this. Mr. David Mushet, whose great practical and theoretical knowledge entitles his opinion to the greatest respect, supposes that the carbon contained in cast-iron and in steel, exists in very different states; and that steel is a combination of iron with pure carbon, similar to the diamond, but that crude iron, is iron containing the oxyd of carbon, which is charcoal. This opinion he founded upon the result of a very numerous series of experiments, many of which he communicated to the Philosophical Magazine, vol. xiii. He found that a piece of Swedish bar-iron, weighing 885 grains, introduced into a Stourbridge clay crucible, and half its weight (442 grains) of charcoal well prepared; a clay cover, fitting exactly, being placed on, and the whole exposed to a moderate heat for half an hour; that the result was, a perfect button of super-carbonated crude iron, weighing 928 grains, which therefore had gained $\frac{1}{20}$th on its original weight; while the charcoal, which remained in the crucible in an intensely black state, weighed 290 grains, having lost 34.4 *per cent.* of its original weight.

In a second experiment, made in a similar manner, but with only a quarter of the charcoal, the iron gained $\frac{1}{19\frac{9}{10}}$ of its original weight, and the loss in charcoal was 45 *per cent.*: the metal was richly carbonated. When one-sixth of charcoal was used, the iron produced, resembled the produce of No. 1. and 2. of the crude iron of commerce; its weight was increased $\frac{1}{20\frac{1}{4}}$; and 57 *per cent.* of the charcoal disappeared in the process.

With one-eighth of charcoal, the iron gained $\frac{\quad}{22}$ of its

original weight; and the weight of the charcoal which diſappeared was $67\frac{7}{10}$ *per cent.* The metallic button was very highly carbonated, and apparently formed an entire maſs of carburet.

One-ninth of charcoal produced a ſuper-carbonated button of crude iron, rather inferior to the preceding in point of carbonization: its ſurface was ſmooth, and of a dull lead-colour, entirely free from the uſual ſhining ſpecks of carburet, which very rich crude iron contains upon its ſurface. It had gained equal to $\frac{1}{18}$th in weight by the fuſion; and the loſs in charcoal was 80 *per cent.*

When treated in the ſame manner with $\frac{1}{12}$th of its weight of charcoal, the iron gained weight equal to $\frac{1}{77}$ parts: and 83.5 *per cent.* of the charcoal diſappeared in the proceſs. The metallic button poſſeſſed an uniformly ſmooth ſurface, partially covered with carburet.

One-fifteenth part of charcoal, expoſed with the iron to a heat ſufficient to melt it, was all loſt; the metal gained $\frac{1}{30}$th in weight, which was exactly half the weight of charcoal loſt. The ſurface of the button was not carbonated, as the foregoing experiments: the colour was blueiſh-black, ſmooth in the centre, but a little oxydated towards the edges. The fracture was that of cloſe dark-grey crude iron; the cryſtals much cloſer and more minute than in the preceding experiments. Its quality was ſuch as manufacturers term No. 2. grey melting pig-iron.

When only $\frac{1}{20}$th part of charcoal was employed, none of which remained after the fuſion, the iron gained $\frac{1}{41}$ parts in weight: a ſmall portion of amber-coloured glaſs was found round the edges of the button. The fracture of the metal was ſmooth ſilvery-white, occaſionally ſtudded with carbonaceous ſpecks in form of ſmall grains: it exactly reſembled mottled pig-iron.

With $\frac{1}{25}$th part of charcoal, the metal gained $\frac{1}{61}$ parts in weight, the whole of the charcoal diſappearing. The upper ſurface of the button was ſmooth, but the under conſiderably pitted. The concaves were chequered with the rude cryſtallization peculiar to caſt-iron. Its fracture was bright ſilvery-white, deſtitute of grain, and exhibiting a very perfect ſtreaky cryſtallization ſlightly radiated: its reſemblance was ſtrikingly ſimilar to that of highly-blown crude iron, prepared in the finery for making malleable iron.

A piece of Swediſh iron was placed in $\frac{1}{30}$th its weight of charcoal: the fuſion of the mixture produced a metallic button weighing $\frac{1}{137}$ parts more than the iron employed, which increaſe is not quite a quarter of the loſs in charcoal, which wholly diſappeared in the experiment. The upper ſurface of the button was ſmooth without configuration, but the under ſurface was uneven, and covered with minute but perfect cryſtallization: its fracture was blueiſh ſilvery-white, compoſed of flat dazzling cryſtals, proceeding in lines from a centre to the edges of the button. Here it was evident, that from the ſmall proportion of carbon combined with the iron, it was found to aſſume the earlieſt ſtage of granulation approaching to the ſtate of ſteel. The brilliant concretions obſervable in the ſurface of the button were too indiſtinct and flat for ſteel capable of bearing the hammer.

When the proportion of the charcoal was reduced to $\frac{1}{40}$th of the iron, its conſequent increaſe was but $\frac{1}{180}$th part. The upper ſurface of the button was ſmooth, with a faint impreſſion of a chequered cryſtallization: the under ſurface poſſeſſed ſome large pits ſimilarly though more perfectly cryſtallized; the fracture was one ſhade of blue beyond the laſt experiment. A regular granulated ſurface, compoſed of flat oblong cryſtals, was obſervable, ſtill too indiſtinct and too much on edge for workable ſteel.

With only $\frac{1}{50}$th of the weight of charcoal, the button was deficient $\frac{1}{364}$th part of its weight originally uſed, yet the whole of the charcoal was loſt. The ſurfaces of this button were uniformly ſmooth; the fracture denſe, and diſplaying a grain peculiar to highly ſaturated bliſtered ſteel. When put under the hammer with a low red heat, it withſtood a few blows, but afterwards parted.

Charcoal $\frac{1}{60}$: the metallic button weighed $\frac{1}{31\frac{6}{10}}$ leſs than the iron employed. Its ſurface was wavy and cryſtallized: the under ſurface was rough, and contained one large pit accurately cryſtallized: the fracture was regularly granulated, ſmall but diſtinct, and of a light blueiſh colour. The cryſtals, though diſtinct, were not ſo prominent as thoſe of eaſy drawing caſt-ſteel; it however hammered with the uſual degree of caution neceſſary in the working of caſt-ſteel. The bar of ſteel formed from the button was very proper for file-making, and other purpoſes requiring highly converted ſteel.

The proportion was reduced to $\frac{1}{100}$th part the weight of iron: the produce was $\frac{1}{22\frac{8}{10}}$ leſs than the original weight of iron. The ſurface of the button was ſmooth, without cryſtals: the under ſurface rough, and poſſeſſed of one large pit in the centre, faintly marked with the uſual cryſtalline appearance. The fracture preſented regular light-blue grains, diſtinct and more prominent than in the laſt experiment. One half of this button was drawn into a neat ſquare bar, and proved excellent ſteel. One end of it, being looſe and ſhaled, welded tolerably well, and hardened afterwards with a low heat. From its quality, it ſeemed adapted for manufacturing penknives, razors, &c. poſſeſſing neither the extremes of hardneſs nor ſoftneſs.

Mr. Muſhet continued this ſeries of experiments till the proportion of charcoal became ſo ſmall as $\frac{1}{200}$th part; and he gives the following concluſions, deduced from the reſults.

	Parts by Weight.
Iron ſemi-ſteelified is made with charcoal	$\frac{1}{150}$
Soft caſt-ſteel, capable of welding, with	$\frac{1}{120}$
Caſt-ſteel for common purpoſes, with	$\frac{1}{100}$
Caſt-ſteel requiring more hardneſs, with	$\frac{1}{90}$
Steel capable of ſtanding a few blows but quite unfit for drawing, - - -	$\frac{1}{50}$
The firſt approach to a ſteely granulated fracture, is from - - -	$\frac{1}{30}$ to $\frac{1}{40}$
White caſt-iron - - - - - -	$\frac{1}{25}$
Mottled crude iron - - - -	$\frac{1}{20}$
Carbonated crude iron - - -	$\frac{1}{15}$
Super-carbonated crude iron - -	$\frac{1}{12}$, or

when any greater quantity is combined with it.

In the above experiments it will be ſeen, that when more than $\frac{1}{40}$th part of charcoal is employed, the weight of the produce is increaſed; but when leſs than $\frac{1}{40}$th part is uſed, a loſs is experienced proportioned to the diminution of the carbon. The increaſe of weight in the iron is by no means equal to the loſs in the charcoal, never exceeding the half thereof; but this is accounted for in other experiments made by Mr. Muſhet, where charcoal was found to be tranſmitted through cloſe crucibles in a high degree of heat.

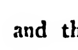
The French chemiſts made a direct experiment to prove, that the diamond is really carbon in a cryſtallized ſtate. By incloſing a ſmall diamond in a piece of malleable iron, and melting this in a cloſe crucible, it was found to be converted into ſteel, and the diamond had diſappeared.

The manufacture of *natural ſteel* is carried on in Germany, and Swedenborgius gives us the following account of the method uſed in Dalecarlia for making ſteel from caſt-iron.

The ore from which the crude iron to be converted into steel is obtained, is of a good kind; it is black, friable, and composed of many small grains: it produces very tough iron. The conversion into steel is made upon a forge-hearth, something smaller than that commonly used for converting cast-iron into malleable iron: the sides and bottom are made of cast-iron; the tuire is placed with very little inclination on one of the side-plates; the breadth of the fire-place is fourteen inches, its length is greater; the lower part of the tuire is six inches and a half above the bottom: in the interior part of the fire-place, there is an oblong opening for the flowing of the superfluous scoria.

The workmen first put scoria on the bottom, then charcoal and powder of charcoal, and upon these the cast-iron, run or cut into small pieces. They cover the iron with more charcoal, and excite the fire. When the pieces of iron are of a red white, and before they begin to melt, they stop the bellows, and carry the mass under a large hammer, where they break it into pieces of three or four pounds each: the pieces are again brought to the hearth, and laid within reach of the workman, who plunges some of them into the fire and covers them with coal. The bellows are made to blow slowly till the iron is liquefied, when the fire is increased; and when the fusion has been long enough continued, the scoria is allowed to flow out, and at that time the iron hardens. The workman adds more of the piece of crude iron, which he treats in the same manner, and so on a third and fourth time, till he obtains a mass of steel of about a hundred pounds, which is generally done in about four hours. This mass is carried to the hammer, where it is forged and cut into four pieces, which are further beat into square bars four or five feet long. When the steel is thus forged, it is thrown into water, that it may be easily broken, for it is yet crude and coarse-grained. The steel is then broken in pieces, and carried to another hearth, similar to the former. These pieces are laid regularly in the fire-place, first two parallel, upon which seven or eight others are placed across; then a third row across the second in such a manner, that there is a space left between those of the same row: the whole is then covered with charcoal, and the fire is excited. In about half or three quarters of an hour the pieces are made hot enough, and are then taken from the fire one by one, to the hammer, to be forged into little bars from half a foot to two feet long, and while hot, are thrown into water to be hardened. Of these pieces, sixteen or twenty are put together, so as to make a bundle, which is heated and welded, and afterwards forged into bars four inches thick, which are then broken into pieces of convenient length for use.

Converting of Steel by Cementation with Charcoal.—The quality of steel is intimately connected with that of the iron from which it is converted, and the iron made in Sweden is esteemed the best for the purposes of cementation. This process is almost wholly in the hands of the English, who pay a higher price for the iron, and by that means secure nearly all the iron of Roslagia, which is the best iron of Sweden.

The best marks of Swedish iron are: that called the hoop L, which is denoted by a circle, with an L in the centre; thus,  the G L; thus, : the double bullets thus, . The iron of these three marks bears nearly the same price, which is sometimes as high as 40*l.* *per* ton. There are also the Swedish marks; as P L, (the hoop S, : and the gridiron, ; which are worth few pounds *per* ton less than the former; *viz.* from 34*l.* to 38*l.*, when the best marks are 40*l.*

The Russian marks are, first, that called the C C N D: the mark is six Russian letters, C H E H P B, worth about 37*l.* *per* ton, when the others are at 40*l.*: and the P S I, which is marked by the Russian letters P S I, is so inferior, as to sell for only 26*l.* or 27*l.*

It is to be lamented that, in the present state of our iron manufacture, we are unable to produce malleable iron which is equally fit for converting into steel with the Russian and Swedish iron. The general opinion upon this deficiency is, that it arises from some superiority in the foreign ores of iron, but more immediately from the circumstance of their using charcoal of wood instead of the coke of pit-coal in smelting or reviving them; and some of our manufacturers do not hesitate to assert, that they can make iron with charcoal equal to the foreign in quality; but that in respect to price, the circumstances of this country will not allow them to cope with those countries, where the destruction of wood is in some measure considered as beneficial, by clearing the land for the operations of husbandry.

The Swedish and Russian iron is imported into this country by iron merchants in immense quantities together, this trade being in the hands of a few individuals: by them it is retailed in smaller portions to the converters, whose furnaces are chiefly about Sheffield and at Newcastle, who, after cementation, dispose of the greater part of it to the manufacturers of steel goods in the state of blistered bars. Its value is estimated by the Swedish or Russian marks of iron, which still remain upon the bars. The manufacturers send their bars to the tilt-mills, where they are made into common steel and shear or German steel, or they melt it to form cast-steel.

The conversion of iron into steel is performed in a furnace, hence called a converting furnace. The external building is a large and tall cone, similar to a glass-house, within which, one or two large crucibles, called pots, are placed, and surrounded by flues in a manner best calculated to communicate a constant and regular heat to every part of them. In these pots the iron bars are placed, being stratified in pulverized charcoal, and the pots are covered over with sand to exclude the external air.

A more perfect idea of the converting furnace will be had by referring to *Plate* VII. *of Iron Manufacture*, which contains a horizontal plan and two vertical sections of one of the furnaces used in the neighbourhood of Sheffield, with two pots for containing the iron. In all the figures, the same letters of reference denote the same parts. C C is the external cone, built of brick or stone work; its diameter at the base varies in different furnaces, according to the size of the pots it contains: its extreme height from the ground to its vertex should not be less than forty or fifty feet to cause a proper draught. To create a sufficient heat for the process, the top of the cone usually terminates with a cylindric chimney of some feet in height. The conical form of the external building is by no means essential; any form will operate in the same manner, if it is of a proper height: some are in practice built nearly in the shape of the small end of an egg, with a round chimney upon the top. The lower part of the cone is built square or octangular, as is the plan of *fig.* 3. The sides are carried up until they meet the cone, giving the furnace the appearance of a cone cut to a square or octangular prism at its base, and exhibiting the parabola where every side intersects the cone.

The conical building contains within it a smaller furnace,

called the vault, built of fire-brick or ſtone, which will withſtand the action of a moſt intenſe heat, without cracking or vitrification. D D in the ſection is the dome of the vault, and E E its upright ſides, the ſpace between which, and the wall of the external building, is filled up with rubbiſh and ſand. The vault, as is ſhewn in the plan, is always four-ſided, that it may contain the pots which receive the iron bars to be converted. A B repreſent the two pots, built of fire-ſtone, each ten feet long, three feet deep, and two feet nine inches wide; the ſpace between them is twelve inches wide; and directly beneath it is the fire-grate. The pots are ſupported by a number of detached courſes of fire-brick, as ſhewn at *e e* (*fig.* 1.) which leave ſpaces between them, called flues, to conduct the flame under the pots: in the ſame manner, the ſides of the pots are ſupported from the vertical walls of the vault, and from each other, by a few detached ſtones, (*f*, *fig.* 1.) placed ſo that they may intercept as little as poſſible of the heat from the contents of the pots. The adjacent ſides of the pots are ſupported from one another by ſmall piers of ſtone-work, which are alſo perforated, as ſhewn at *d* (*fig.* 2.) to give paſſage to the flame. The bottoms of the pots are built of a double courſe of brick-work, about ſix inches thick; the ſides neareſt together are built of a ſingle courſe of ſtone, about five inches in thickneſs; and the other parts of the pots are ſingle courſes about three inches, the ſides not requiring ſo much ſtrength, becauſe they have leſs heat and preſſure to reſiſt.

The vault has ten flues or ſhort chimneys, F F, riſing from it; two on each ſide, to carry off the ſmoke into the great cone, ſhewn in the plan 3, communicating with each ſide, and two at each end.

In the front of the furnace, at H, an aperture is made through the external building, and another correſponding in the wall of the vault: theſe openings form the door, at which a man enters the vault to put in or take out the iron: but when the furnace is lighted, theſe doors are cloſed by fire-bricks luted with fire-clay. Each pot has alſo ſmall openings in its end, through which the ends of two or three of the bars are left projecting in ſuch a manner, that by only removing one looſe brick from the external building, the bars can be drawn out without diſturbing the proceſs, to examine the progreſs of the converſion from time to time: theſe are called the tap-holes; they ſhould be placed in the centre of the pots, that a fair and equitable judgment may be formed from their reſult of the reſt of its contents.

a b, in the elevation, is the fire-grate, formed of bars laid over the aſh-pit I, which muſt have a free communication with the open air, that it may convey a current of freſh air to ſupply the combuſtion. The aſh-pit ſhould alſo have ſteps down to it, that the attendant to the furnace may get down to examine by the light, whether the fire upon the whole length of the grate is equally fierce; and if any part appear dull, he uſes a long iron hook to thruſt up between the bars and open a paſſage for the air. The fire-place is open at both ends, and has no doors. The fire-grate is laid nearly on a level with the floor of the warehouſe, before the furnace, and the fireman always keeps a heap of coals piled up before the apertures at its ends, ſo as to cloſe the opening. This forms a very ſimple and effective door; and when the furnace requires a freſh ſupply of fuel, a portion of the heap of coals is ſhoved in by a ſort of hoe, and the heap renewed, to ſtop any air from entering into the furnace, except that which has paſſed upwards through the ignited fuel, and by that means contributed to the combuſtion.

The fire-ſtones that compoſe all thoſe parts of the furnace which are expoſed to the action of the heat, are firſt hewn nearly to ſize, and finiſhed by grinding two ſurfaces together, ſo that they make very perfect and cloſe joints: when laid together, they are cemented with well-tempered fire-clay, mixed up very thin with water. The fire-clay which anſwers beſt for this purpoſe, is that brought from Stourbridge, in Staffordſhire, and is the ſame of which the celebrated Stourbridge crucibles are compoſed; but very good fire-clay for the purpoſe is procured from Birkin-lane, near Cheſterfield. When the furnace has been once burnt, this clay becomes equally hard with the ſtone, and is leſs liable to fly or vitrify in an intenſe heat, than any other known cement.

The proceſs of charging the furnace with iron for converſion is conducted as follows. The bars of iron are firſt cut to the length of the pot; and for this purpoſe an anvil is placed at ſuch a diſtance from the wall of the building, that the diſtance from the edge of a cold chiſſel wedged into the eye of the anvil, to the wall, will be juſt the length of the pots. One workman places the end of a bar againſt the wall, and lays the other end acroſs the edge of the chiſſel, whilſt another with a ſledge-hammer ſtrikes upon the bar till it is cut half through; then it is turned the other ſide upwards, and the end cut completely off. By this gauge the bars are all cut to one length, and a man enters through the door in the vault, to diſpoſe of them in the pots: he is provided with a baſket of fine pulverized charcoal, a ſieve, and a ſhovel. An iron plate is put into the furnace, and lays over the ſpace between the two pots to form the floor, upon which the man ſtands while at work. He commences his operations by ſifting a layer of charcoal over the bottom of the pot, about half an inch thick, and he is careful in uſing the ſieve to lay the charcoal of an even thickneſs in every part; but if it ſhould not be carefully done, he levels it with the ſhovel. The workman on the outſide now introduces the bars into the furnace through a hole, made by taking out a brick in the wall, juſt over the end of one of the pots, and the workman within depoſits them upon the ſtratum of charcoal in the bottom of the pot, arranging them parallel to each other, and leaving an interval of about an inch between each bar. When the bottom of the pot is in this manner covered with iron bars, charcoal is again ſifted upon them, and levelled with the ſhovel, to fill up the intermediate ſpaces between the bars, and to cover them about an inch thick: another layer of bars is then introduced into the furnace, placed upon the charcoal, and in its turn covered over with a ſtratum of charcoal; and in this manner the pot is filled to within two inches of the top. A layer of the ſand which is found in the bottom of grindſtone troughs, is then ſpread three or four inches thick upon the whole, to cover the pots up cloſe, and prevent the acceſs of the common air and flame. In placing the ſucceſſive layers of bars in the pot, it is proper that each ſhould be laid over the ſpace between two of the bars in the layer beneath, becauſe each bar will then be ſurrounded by a greater thickneſs of charcoal, than it would if they were laid directly over each other. Two or three of the bars ſhould be left ſomewhat longer than the reſt, and their ends ſhould project through the trial-holes in the ends of the pots, and ſand rammed round them in the holes to keep out the air.

The pots being both filled and covered up with the ſand and rammed down, the holes for introducing the bars are cloſed by a brick or fire-ſtone, and luted with fire-clay. The apertures through the outer wall oppoſite the ends of the trial-holes are alſo ſtopped and luted. The iron plate upon which the man ſtood is now removed, and the doors in the vault cloſed up by bricks ſet with fire-clay; next, the opening in the external building is ſhut up, and the furnace is charged ready for lighting.

The furnace is kindled by lighted wood placed on the fire-grate, then a few coals are thrown in, and when well lighted, the quantity is increaſed; the heat thus generated rarefies the air contained in the vault and in the great cone;

and being thus rendered of lefs fpecific gravity than the external air, it rifes up in the cone, and a frefh fupply rufhes in through the bars of the grate, to reftore the equilibrium. By going through the fire, this air parts with its oxygen, and excites the combuftion, and becoming heated, rifes up the chimney, and caufes a very ftrong draught of air to enter the fire.

At firft kindling, the fuel is fupplied in fmall quantities, that the heat in the furnace may be gradually increafed, and not endanger the cracking of the ftones: in a few hours time the quantity of fuel is increafed, fo as to produce the full heat, which is to be maintained as equally as poffible throughout the whole procefs. The fuel, which is pit-coal, is introduced at both ends of the grate, through fmall arches in the wall, which are in a line and on a level with the fire-grate, a quantity of coals being always left before the end of the arch to ftop it up, and prevent any air getting into the furnace, without paffing through the grate. Part of thefe coals is forced into the furnace, as before mentioned, when it requires a fupply of fuel, which is generally at intervals of about half an hour each. The fireman frequently examines the appearance of the under fide of the fire-grate, and judges from it the ftate of the fire: he improves it where neceffary, as before defcribed, by thrufting a hook up between the bars to make way for the air.

The flame arifing from the ignited fuel upon the grate partly proceeds upwards between the pots, and heats them by that means; it then ftrikes the roof of the vault, and is reverberated down upon the pots, and efcapes through the fix flues or chimnies in the vault. The draught alfo draws the flame from the grate under the pots, and round the outfide and ends. The principal object in this ftage of the procefs, is to maintain the fame degree of heat in every part of the pot, that every bar may be equally converted in the fame fpace of time. The roof of the vault muft be built of very good ftone (none being better than from Roches quarry, in Afhover), to withftand the great heat exerted upon it: it is cuftomary to build them very thin, and cover the outfide with a fmall thicknefs of dry fand to keep them tight, in cafe of a ftone cracking.

In this way the fire is kept up in as equable a manner as poffible, until the iron is fuppofed to have imbibed a fufficient portion of carbon from the charcoal to render it fit for its intended purpofe: in this circumftance, the manufacturer regulates his judgment by his experience of former proceffes. About the time that he fuppofes the converfion to be fufficiently advanced, one of the trial-bars is drawn out from the pot, and by comparing the fize of the blifters raifed upon its furface with another bar which is known to be fufficiently carbonated, an idea is formed of the ftate of the furnace, and accordingly the fire is, at the proper time, difcontinued, and the furnace is fuffered to cool. Some manufacturers proceed to make experiment of the trial-bar by hardening and tempering it, fo as to prove to a certainty the degree of its converfion, the blifters being found in fome degree fallacious; for their fize depends as much upon the degree of heat to which the bar has been expofed, as upon its carbonization, and fhew the rapidity with which the converfion has been carried on, rather than its actual ftate.

The time which the iron is required to be in the procefs of cementation depends upon a variety of concurring circumftances. 1. The degree of carbonization required to form a fteel of the proper quality; this varies with the ufe the fteel is to be applied to. 2. The heat it is fubjected to. 3. The nature of the iron employed in the procefs. The combinations of thefe circumftances are fo numerous, that nothing but long experience can determine the proper duration of the procefs.

In general terms it may be obferved, that a fhort period will produce a fteel very foft and tenacious, which, when properly treated, will poffefs elafticity as its moft ftriking property, and is therefore very proper for fprings, wire-drawing, and other purpofes requiring ductility, but without the hardnefs requifite for edge-tools. The period of cementation for fuch fteel varies in different manufactories, from four to fix days and nights.

Steel which requires more hardnefs, but at the fame time fufficient tenacity to refift fudden fhocks, fuch as the edge-tools for working wood are fubject to, muft be cemented a longer time. This, which is moftly tilted into fhear fteel, is cemented fix, feven, or eight days, according to the heat and the quality of iron employed. The fteel employed for fabricating tools for cutting metals and hard fubftances being but fmall in demand compared with the others, is not cemented a longer time, but is returned into the furnace at the next charge, along with a charge of iron, and cemented again with frefh charcoal: this is termed double converted fteel. But for fome few purpofes, fuch as the turning and boring of caft-iron, the fteel is converted three times: in this ftate it becomes fo hard and brittle as to be totally unfit for any purpofe requiring tenacity, or for any cutting edge which is lefs than an angle of 70 degrees, or it would be continually breaking.

The heat which is requifite for the procefs, muft be as great as to give the iron nearly a welding heat, but if carried farther, will endanger melting the bars when the procefs has proceeded fome time; an accident which has frequently occurred through the inattention of the fireman. It is obferved by manufacturers, that the carbonization proceeds quicker when the heat is greateft, and for this reafon the duration of the procefs varies in different furnaces, in fome meafure from their conftruction, in urging a greater heat, and this depends chiefly upon the height of the chimney, and the draught it occafions.

When the converfion is fuppofed to be complete, the furnace is fuffered to cool, until a man can conveniently enter the furnace, to take out the bars and remaining charcoal, and prepare the furnace for a new charge. The bars which are brought out are (from being covered with blifters upon the furface) termed bliftered fteel.

On examination of the fracture of a bliftered bar, it is found full of internal cracks, which are generally parallel to the flat fide of the bar: fome of them are larger than others, and extend the parts of the bar fufficiently to raife numerous protuberances or blifters upon its furface. Thefe cracks have every appearance of being opened by the expanfive force of fome gas generated in the iron during the procefs, but what the nature of this gas is, ftill remains to be inveftigated. It feems to arife from the body of the iron itfelf, by the crack being within the folid fubftance of the bar. The fracture of the bliftered fteel is exceedingly irregular, of a white colour, like frofted filver, and appears like an irregular cryftallization; but the facets exhibited are larger in proportion as the cementation has been longer continued, and from this reafon they are larger towards the furface of the bar than in its centre.

The furnace above defcribed is of that kind which is efteemed the beft for the procefs, and is moft generally employed in and about the neighbourhood of Sheffield in Yorkfhire, where the manufacture of fteel is carried on in a larger fcale than in any other part of England. The furnaces ufed at Newcaftle, which is another feat of this trade, are very fimilar.

The charge confifts of twelve tons, each pot containing fix tons of iron; and it is neceffary that all the bars converted

at one procefs be of the fame fize, or the fmaller ones would be thoroughly converted before the others had taken up a fufficient dofe of carbon. This large quantity of a fingle article is more than the trade of fome manufacturers will difpofe of, they therefore employ fmaller furnaces, which contain only eight tons, and fuch are generally conftructed but with one pot ten feet in length, three feet broad, and two feet deep: the fire-place is directly beneath the pot, twenty inches wide, and flues are carried round it on both fides and ends: the vault and chimney of fuch a furnace are the fame as the double pot. It is found by experience that the fmall furnaces confume fomewhat more fuel in proportion to the quantity of iron they convert, than the large ones, becaufe the heat loft in the beginning and end of the procefs, and that tranfmitted through the walls of the building, is the fame in both inftances.

Mr. Daniel Little of America, in 1785, recommended a new fubftance to be ufed in the cementation of fteel inftead of charcoal: it is the marine plant known by the name of rock-weed, or rockware, and is found in great plenty on rocky fhores in America. It was to be prepared by firft mowing it from the rocks by the fcythe or fickle, and fpreading it out on dry land till the rains have wafhed off the greater part of the fea-falt; it was then to be dried and pulverized, and may be ufed as any other cement for making of fteel. He fays that he difcovered this property in an experiment where a fmall piece of iron was put into a crucible, and filled with the powdered plant as a cement: after it had been expofed to little more than a cherry heat for five or fix hours, it was converted into fteel.

All cemented fteel in its raw ftate, after it is taken from the converting furnace, is called bliftered fteel; becaufe the furfaces of the bars are covered with blifters, and on breaking a bar it is found to be full of cavities withinfide, which feem to have been opened by fome gas generated in the iron when in the procefs of cementation, and to have raifed the furface into blifters, which are hollow within. In this ftate the fteel is not fit for any purpofe, becaufe of thefe numerous cavities, and from the great difpofition it has to break with the moft irregular and rugged fracture imaginable. To render it found and tenacious, it muft be well hammered while at a moderate heat, which operation is termed *tilting the fteel*, becaufe it is done under the tilt-hammer, worked by machinery. There are many reafons why the hammering of fteel cannot be fufficiently performed by hand: the principal are, that the expence of labour would be too great to anfwer, and that a man could not ftrike hard and quick enough, to complete the operation at one heat of the fteel: if more than one heat is taken, the fteel will not receive fo much advantage from the hammering, becaufe when it is heated, its pores are opened; and if fuffered to cool without hammering, the grain of the fteel will be found confiderably coarfer; therefore, every time it is heated, the good effects of the previous hammering are in a great meafure loft. Tilt-hammers are worked by water-wheels or fteam-engines, according to the local fituation of the manufactory. (See a defcription in the article TILT-*Hammer*, *Plate* VIII. *Iron Manufacture.*) The fame axis is made to actuate three or four tilt-hammers placed fide by fide, and the hammers are not all of equal lengths, each one being fhorter than the next: by this arrangement, when they are all working together, the workman of one tilt does not incommode thofe employed at the other two. The anvils of the hammers are nearly on a level, or at moft only a few inches above the furface of the ground; and the workman fits in a pit or foffe, dug for the purpofe, in a direction perpendicular to the helve of the tilt, upon a feat which is fufpended from the roof of the building by two iron rods: by this means he can with the greateft eafe advance to or from the hammer, by juft touching the ground with his foot, and pufhing himfelf backwards or forwards as he fits in the fwing. The three feats are in parallel directions, but fufficiently diftant from each other, in confequence of the different lengths of the hammers, to allow the workmen to perform their bufinefs. At a convenient diftance from each tilt, is placed the forge for heating the fteel. The two forges for the fmall hammers are placed together under the fame dome, while the other forge is by itfelf near the great hammer. The bellows for the forges are worked by a fmall crank on the end of the gudgeon of the fhaft; they are placed over-head in the roof of the building, and a copper pipe conveys the air to the tue iron. The forges are like thofe ufed by fmiths, except that they have a fmall cover built of fire-brick over the hearth: the cover is fquare within, about eight inches wide, eight high, and eighteen inches or two feet long. It is open in front, to introduce the bars. The coals are placed on the hearth, as fmiths ufually do, and the brick cover acts, to reverberate the flame down upon the fteel, and give a very regular heat. Each workman at the tilt is attended by two boys, who heat the fteel at the forge, and convey it to the workman, that he may lofe no time: another boy attends each tilt to take away the finifhed rods and cut them to length, and then to ftraighten them.

The operations of the tilt are conducted in the following manner: Suppofe a piece of fteel has been heated by one of the boys, and brought to the man at the hammer, he places it upon the anvil, at a part neareft to the centre of the hammer, where its furface is reduced to a round edge, about an inch wide: the face of the hammer is made round, to correfpond with the anvil, and from its fimilarity to the edge of a fmith's hammer, may be called the pen of the hammer and anvil. The machine is always in rapid motion, and between every ftroke that the hammer makes, he moves the bar forwards on the anvil, that it may be ftruck by the edge of the hammer in a frefh place. If the bar is flat, as bliftered fteel ufually is, it is firft hammered in this manner upon its edge, to reduce it to a fquare, and at the fame time draw it out in length. When it has been hammered thus all its length, the furface becomes indented on both fides by the edges of the hammer, the anvil being bounded by waving lines. This firft operation is called *notching down*. The tilter then removes the bar beneath the flat face of the hammer, and the rod is flattened at every ftroke, and all the indentation removed; when he gradually recedes from the hammer, drawing the rod along, and flattening it all the way. When the end of the rod comes under the hammer, he turns the other face of the rod upwards, and advancing to the hammer, pufhes the rod forwards under it: in this manner he proceeds, flattening it on one fide or the other, until he brings it to the proper fize, which he tries by a gauge. The moment it is finifhed, the boy brings another piece of hot fteel, which he places under the hammer, and then the other boy takes away the finifhed rod from the tilter, who takes the frefh piece: in doing this, they are careful that the hot piece of fteel is placed under the hammer before the other is taken away, that the faces of the hammer and anvil may not ftrike together, when there would be danger of breaking them, as they are both made of caft-iron: the fecond piece is tilted in the fame manner as before, and when finifhed, is changed for another.

The perfection of tilting fteel, depends upon drawing out a rod perfectly ftraight to the fame fize in every part of its length. Many workmen, particularly at Sheffield, have acquired fuch fkill and dexterity in the management of the rod while under the tilt, that their work is as ftraight and even

as though it had been drawn through a fteel-plate, in the fame manner as wire, and all its angles perfectly fquare: its furface is of a black polifh, and as fmooth as though it had been filed. All artifts ufe the fquare fteel rods for making their tools; and the ftraightnefs and regularity of the rods are fuch, that a perfon who has not been an eye-witnefs of the operation, would fcarcely believe it poffible to produce fuch accurate work from the blows of a hammer. The points to be attended to by a tilter are, that in notching down the bar to draw it out to length and fize, he caufes the blows to fall exactly at equal diftances from each other, unlefs (which feldom happens) the bar fhould have any part thicker than the reft; the ftrokes muft then be a little nearer together in that place, to reduce it all to one fize. Afterwards, to flatten the bar, he muft be careful to place the bar truly flat upon the anvil, and hold it in the fame place, whilft he draws the bar under the hammer, and that he moves himfelf with a perfectly equable motion, that every part of the bar may be alike fubjected to the action of the hammer: the furface will then be true, and free from undulations. Another circumftance to be attended to is, when he turns the bar upon the anvil to hammer the adjacent fides, that he makes them truly fquare to the former fides. Thefe things muft all be done in fo little time, that it requires long practice and experience to perform them well. Beginners are always apt, when they place their feet on the ground, to move themfelves too quick juft at that time, which caufes the bar to be thicker at that place.

The different methods of conducting the operation of tilting, give the fteel different qualities, which are diftinguifhed into 1. Common fteel; 2. Shear or Newcaftle fteel, alfo called German fteel; and 3. Tilted caft fteel.

Common fteel is made by tilting bars of bliftered fteel, and drawing them out into rods of any fize. The bliftered bars are of various fizes, but in general about an inch and a half broad by half an inch thick. If thefe are to be drawn into rods half an inch fquare, they are broken into convenient lengths to handle, and one end of each piece is heated to a good welding heat by the boy who attends the forge, who puts three or four in the fire together, and, according to their fize, he learns by experience at what time he muft put every one into the fire, that it may acquire the proper degree of heat by the time that the tilter fhall have juft finifhed the other bars.

The tilter firft begins by notching down the narrow edge of the bar, holding the other end of it in his hand, and notches down fuch a length of it as experience teaches him will be fufficient to form a rod of the length and fize required. The notching on the edge of the bar rather increafes its thicknefs, while it diminifhes its breadth, and brings it nearly to the fquare figure of a rod: he then flattens it, and begins again to notch it down upon the broad fide; afterwards he again flattens it; then proceeds to notch it upon the edge, and afterwards to flatten it once or twice on both fides, and the rod is finifhed.

When a fkilful tilter has been fome hours at work upon rods of one fize, he judges by fight when the rod is of the proper fize; but on firft beginning, he tries it by a gauge, and flattens it repeatedly, if neceffary, the boy bringing a piece of hot fteel to place under the hammer while he is gauging, and which is drawn out in its turn. When the tilting is completely finifhed, the fteel rod is taken away by another boy, who, with a pair of fhears, cuts off the rod from the bliftered bar from which it was drawn out. He places the rod on a flat caft-iron table, and fets it truly ftraight by a hammer, then ftamps the bar with a mark of the quality of the fteel, and it is finifhed.

All thefe operations are performed in fo fhort a time, that the rod ftill retains a red heat; but this will excite lefs furprize when it is confidered that the hammer ftrikes four hundred blows *per* minute, and falls with great weight, fo that it foon completes the work, and it is very probable that the great percuffion it exerts upon the fteel in fome meafure preferves the heat. It is well known that blackfmiths are in the conftant habit of lighting a match to kindle their fire, by only hammering a fmall piece of iron quickly, and turning it about under the hammer, and in a fhort time it acquires fufficient heat to inflame the fulphur of the match. This heat moft probably arifes from the friction which the hammer caufes amongft the particles of the iron, by rubbing them violently againft one another; and the fmiths obferve, that the iron will not become red-hot if it is always ftruck upon the fame fide; but it muft be turned round, that a new furface may be continually expofed to the action of the hammer.

Shear fteel is fo called, becaufe the fhears for dreffing woollen cloth are made of it. It is alfo called Newcaftle fteel, becaufe formerly made there; and German fteel, becaufe the natural fteel in Germany is treated in the fame way; it is likewife called *faggotted fteel.* To make fhear fteel, the bars of bliftered fteel are broken into lengths of about eighteen inches; then four or more of thefe are laid together with one of double the length, and all four are tied together with pieces of fmall fteel: this is called a faggot, and is placed in the forge, to be heated to a good welding heat; it is then taken to the tilt, and notched down on both fides, to weld all the bars together, and clofe up the internal flaws. The workman holds the faggot by the end of the long bar as a handle: the operation of welding takes but a few feconds, and a fmall rod is then drawn out from a piece of the end, in the fame manner as drawing out common fteel.

Caft fteel is prepared by melting fragments of bliftered fteel, and cafting them into an ingot. (See STEEL.) The ingot is then drawn out under the tilt into the required fize, and the manner of doing this is the fame as for common fteel.

It is the cuftom of the manufacturers of cutlery and fteel goods to purchafe fteel from the converting furnaces in the ftate of bliftered bars, which they fend to the tilt-mills to be drawn out to the fize they require for their ufe: this is done at regular prices. In tilting fteel, a trifling lofs is fuftained by the metal oxydating upon the furface, and throwing off black fcales. The manufacturers are in the habit of allowing 4.6 to 8 lbs. *per* hundred weight for fuch lofs: this latitude is given, becaufe in drawing the bars out into rods of a fmall fize, the wafte muft neceffarily be greater; the metal being much longer expofed to oxydation, and the furface throwing off more fcales.

Tin

TIN, *Stannum, Jupiter*, a whitiſh metal, ſofter, leſs elaſtic, and leſs ſonorous, than any other metal, excepting lead. In the Chaldee language, טין, *tin*, ſignifies *ſlime, mud*, or *dirt ;*

and when the Phœnicians came into Cornwall, and ſaw this metal in its ancient ſlimy ſtate, they called it "the mud;" and hence, ſome have ſaid, the name *tin*, in Cornu-Britiſh *ſtean*, is derived. Some of the ancients called it *plumbum album*, white lead, probably to diſtinguiſh it from common lead; not knowing that it was radically another metal.

This metal, denominated κασσίτερος by the Greeks, and *ſtannum* by the Latins, ſeems to have been known from the moſt remote ages. It is mentioned by Moſes; ſee Numb. xxxi. chap. 22. It was tranſported to the Eaſt from Spain and Britain by the Phœnicians, with which nations they are ſaid to have carried on a lucrative commerce. Homer mentions it; and by Ariſtotle, the epithet Κελτικον, or *Celtic*, is applied to it, indicating plainly the country from which it was procured. See TIN-*Trade of Britain.*

TIN-*Stone*, in *Mineralogy*, is the moſt common ore of tin, and is nearly a pure oxyd of that metal. The colour is brown, which paſſes from a blackiſh-brown to black, and from a red-brown to yellowiſh and greeniſh-white. It occurs cryſtallized and amorphous, and in grains and rolled pieces, varying from the magnitude of a grain of ſand to that of an egg, or larger. The primitive form of the cryſtal is a flat octohedron: the angles are 112° 10′ and 67° 50′. The figure of the cryſtals is ſeldom perfect; ſometimes a rectangular priſm is interpoſed between the pyramids that form the octohedron. The edges and ſummits of the cryſtals are frequently bevelled or truncated, from which a great variety of ſecondary forms is derived. The cryſtals are alſo frequently united, forming compound cryſtals or macles: indeed, ſo numerous are the ſecondary cryſtals of tin, that more than one hundred and eighty forms of ſingle cryſtals have been obſerved, beſides the compound cryſtals, of which there is a conſiderable variety. The ſurface of the cryſtals is commonly ſmooth and ſplendent, but is ſometimes ſtreaked. The ſtructure is laminar, but the laminæ are rarely viſible. The fracture is uneven and imperfectly conchoidal, with a more or leſs ſhining and reſinous luſtre. When the laminar ſtructure is diſplayed, the luſtre is highly ſplendent. The cryſtals are ſemi-tranſparent or opaque, the darker colours being opaque, the lighter ſometimes nearly tranſparent; and the intermediate ſhades are only tranſlucent, or tranſlucent at the edges. The ſtreak is a greyiſh-white. Tin-ſtone is hard, ſcarcely yielding to the knife, and giving ſparks with ſteel. It is brittle and heavy. The ſpecific gravity varies from 6.759 to 6.970.

Before the blowpipe it decrepitates, and becomes paler; when finely pounded and mixed with borax, it is reducible on charcoal to the metallic ſtate.

Tin-ſtone contains the following conſtituent parts, according to Klaproth.

	From Alternon.	Schlackenwald
Tin - -	77.50	75.
Oxygen -	21.50	24.50
Iron - -	0.25	0.50
Silex -	0.75	

Some analyſes of tin-ſtone give from two to three *per cent.* of alumine. The tin-ſtone of Cornwall, dreſſed in the common manner, is reckoned rich if it yield 65 *per cent.* of tin. Tin-ſtone may be diſtinguiſhed from *wolfram* by its ſuperior hardneſs, as it gives ſparks with ſteel; but wolfram yields eaſily to the knife. The powder of tin-ſtone is a greyiſh-white, that of wolfram a reddiſh-brown. It is diſtinguiſhed from *blende* by its ſuperior hardneſs, and its not emitting a ſulphurous odour when pounded. By its greater ſpecific gravity and luſtre, it may be diſtinguiſhed from *garnet*; and from *ſchorl*, by its colour, luſtre, form, and higher ſpecific gravity. This ore occurs in veins and beds, and diſſeminated in granite rocks. The veins interſect rocks of granite, gneiſs, mica-ſlate, and ſlate: tin-ſtone occurs alſo in alluvial ſoil in the diſtricts that contain tin-veins. See STREAM-*Tin*.

Wood-tin is a ſpecies of tin-ſtone, or oxyd of tin, found with ſtream-tin in rolled pieces, which are wedge-ſhaped or reniform, and ſometimes globular. The ſtructure is divergingly fibrous, with concentric laminæ; and from the ſuppoſed reſemblance to the tranſverſe ſection of fine-grained wood, it received its name. The colour is commonly hair-brown or wood-brown, paſſing into yellowiſh-grey. The luſtre is glimmering or ſilky. It is opaque, hard, and brittle: the ſpecific gravity is 6.450. It is infuſible before the blowpipe, but is changed to a browniſh-red colour. When ſtrongly heated in a charcoal crucible, it yields about 75 *per cent.* of metallic tin. The conſtituent parts are, according to Vauquelin,

Oxyd of tin	91
Oxyd of iron	9

In Cornwall, this ore is almoſt always found with ſtream-tin, and never in veins: it is ſaid, however, to have been recently met with in cellular quartz, but in very minute pieces. It is one of the moſt common ores of tin in Mexico, and occurs in veins that traverſe a porphyritic trap, and alſo in alluvial depoſitions. In ſome wood-tin, there is a ſmall, black, ſmooth globule, from which, as from a centre, the fibres diverge: this has received the name of *bird's-eye tin*. Wood-tin, in its ſtructure and mode of formation, probably bears a near analogy to the kidney-ſhaped hematite iron-ore.

Bell-metal Ore, *Tin Pyrites*, or *Sulphuret of Tin*, is an extremely rare ore of this metal, being found only in Cornwall, at Huel rock, in a vein accompanied with ſulphuret of zinc and iron. Its colour is ſteel-grey, paſſing into yellowiſh-white: it has a metallic luſtre, and granular uneven fracture: it yields eaſily to the knife, and is brittle. The ſpecific gravity is 4.350. It fuſes into a black ſlag before the blowpipe, exhaling at the time a ſulphurous odour. It communicates a yellow or green colour to borax. The conſtituent parts differ in different ſpecimens; according to Klaproth, they are as under:

Tin -	34	26.50
Copper -	36	30.
Iron -	3	12.
Sulphur	25	30.50
Earthy matter	2	
	100	99

Klaproth obſerves, that the darker varieties of this ore are conſiderably poorer in tin than the lighter, but the proportion of iron increaſes.

Analyſis of the Ores of Tin.—The analyſes in the *dry way* were made by Klaproth in charcoal crucibles in the following manner, in which the reſults were always found to be conſtant. The ore was broken, and well cleaned from the matrix. One hundred grains were introduced into the cavity of a charcoal crucible, cloſing its orifice with a ſtopper of charcoal. The charcoal crucible was then fitted cloſe into one of baked clay, and placed upon the forge-hearth before the nozzle of the bellows. The contents in the charcoal crucible were reduced to the metallic ſtate by expoſing it to a ſtrong blaſt for half an hour. The button of metallic tin produced was a little blackiſh on the ſides,

and its surface coated with a greenish crust. From one hundred grains of Bohemian tin-stone, seventy-two grains and a half of tin were produced. Wood-tin and stream-tin were treated in a similar manner. Brown tin-stone, exposed to a porcelain fire in a clay crucible, formed a clear dense glass, greenish-grey in the middle, but of a bright yellow on the sides and top. The interior of the vessel was glazed, of a milk-white, and overlaid with many small groups of needle-shaped crystals of a light-brown colour. The inner surface of the lid was lined with similar crystals.

Analysis of Tin-Stone in the humid way.—To Klaproth we are indebted for the discovery of a simple and effectual mode of analysing tin-stone in the humid way. Boil 100 grains of this ore, finely pounded, with a solution of 600 grains of caustic potash. Evaporate to dryness, and then ignite the mass moderately for half an hour. Add boiling water, which dissolves the principal part of the mass, and the residue must again be ignited with six times its weight of caustic potass, and dissolved in water, as before. Add this to the last solution, and saturate the whole with muriatic acid, which will throw down an oxyd of tin. Let this be re-dissolved by an additional quantity of muriatic acid, and precipitated again by carbonate of soda; when lixiviated, and dried in a gentle heat, it acquires the form of bright-yellowish transparent lumps. This precipitate must be finely powdered, and once more dissolved in muriatic acid, assisted by a gentle heat. The insoluble part consists of silex. Dilute the solution, which is colourless, with from two to three parts of water, and introduce a stick of zinc, round which the tin will collect in a metallic state in the form of delicate dendritic laminæ. Scrape off the tin, wash, dry, and fuse it under a cover of tallow in a capsule placed on charcoal. A button of fine metallic tin will remain at the bottom, the weight of which, deducted from that of the ore, indicates the proportion of oxygen.

Analysis of Bell-metal Ore, or Tin Pyrites.—To two drachms of finely powdered ore, add one ounce of muriatic acid, and half an ounce of nitric acid: this will dissolve the greater portion of the metallic part without heat, but a gentle heat must be applied to dissolve the whole. The sulphur will float on the surface of the solution, and must be separated by filtration. To the solution add carbonate of potass, which produces a greenish precipitate; let this be re-dissolved in diluted muriatic acid, and introduce a cylinder of pure tin, the weight of which is to be previously ascertained. By this means the copper will be separated in a metallic state. The cylinder of tin must now be carefully weighed, and the quantity which it has lost must be noted, and a cylinder of zinc must be introduced into the foregoing solution: this will separate all the tin, which must be melted with tallow and weighed. Deduct the quantity of tin which was lost by the cylinder, and the remainder will be the quantity of tin from the ore, held in the solution.

The sulphur separated by the first filtration must be ignited, and the unconsumed residue, dissolved in nitro-muriatic acid, must be added to the solution, in order to obtain the whole of the contents. The undissolved part will be the siliceous matrix.

The copper may be briskly digested in nitric acid, which will leave behind a minute portion of oxyd of tin, and ascertain the precise quantity of pure copper contained in the ore.

The method of getting, preparing, &c. the tin in the Cornish mines, much the best and most considerable in the world, is given us in the Philosophical Transactions, Abr. vol. ii. p. 569, &c. and more distinctly and fully in Pryce's Mineralogy.

The working of the tin-mines is very hard and difficult, not only by reason of the great depth which the veins descend to, even as low as sixty fathoms; but also because the rocks, through which passages are frequently cut, are extremely hard. Nor is the soft shaking earth found in the tin-mines much less inconvenient to the workmen, both by reason of the fetid, malignant vapours it exhales, and of the current of water often met with in them: these disadvantages often render it impracticable for the workmen to hold it above four hours together.

The existence of native tin has been always doubted, and till of late absolutely denied by all mineralogists, both ancient and modern: however, Mr. Borlase, in his Natural History of Cornwall, p. 185, suggested, that its existence was far from being improbable; but he afterwards discovered three specimens of this metal, native or pure, of which he presented an account to the Royal Society. Mr. Mendes da Costa made several experiments on one of these specimens, with a view of proving that it was really tin; from which he infers, that it is perfectly ductile and malleable; and being bent between the teeth, gives the same crackling noise as tin always does: in an open fire it melts easily, calcines on the surface, and smokes; but forced in a stronger fire with borax, it detonates with small phosphorescent sparks, which is a property of pure tin; and it is only corroded to a white calx in spirit of nitre, and oil of tartar *per deliquium* being added to the solution, none of it was precipitated: whence he concludes, that it was pure tin. Philos. Trans. vol. lvi. art. 7. 39. Native tin is also said to have been found in Saxony and Malacca.

The ores of tin may be generally classed into shoad or shode, stream, and bal or mine tin. The shoad is disjunct, and scattered to some distance from its parent lode, and is pebbly or smoothly angular, of various sizes, from half an ounce to some pounds weight. See SHOAD.

Stream-tin ore is the same as shoad, but smaller sized, &c. See STREAM-*Tin* and STREAMING.

Bal or mine tin-ore often rises very rich; and instances frequently occur, in which it has been discovered in the richest and purest state imaginable. This kind of rich ore consists of the blackest grains or crystals, and is usually found at a moderate depth, or within the day-side of forty fathoms.

When the tin-ore is raised, or dug and drawn out of the mine, and laid by the shaft, it is first *spalled*, as the process is termed, which consists in breaking it into smaller fragments, and separating it from the worthless parts. When the best parts are sorted, they are divided into heaps by a hand-barrow, containing a sack and a half, or eighteen gallons. Each of these shares, called *doles*, being turned over, equally levelled and mixed, is then divided with a shovel into two equal parts; and after being bruised by large sledges to the size of a hazel-nut, is equally levelled and divided into four parts: the bruising and divisions are repeated at pleasure, till the quantity designed for sampling is well mixed, and made as fine as common sand. To make a rough guess, or coarse essay, the sampler takes a handful of it, and washes it on a shovel, till the impure parts are carried off by the water, and the more solid and heavy particles, that are left behind, are bruised with a sledge on the shovel, till the whole assumes the appearance of mud. This is again washed, and by a peculiar motion the metallic particles are collected together on the fore-part of the shovel. By repeating these bruisings, washings, and motions, it becomes clean black tin, fit for the smelting-furnace. This is called a *van*, (probably from the French *avant, foremost*,) as it is thrown upon the point of the shovel by the dexterity

of the sample trier. After the tin is thus cleaned, it is dried; and if there be as much black tin as will cover a shilling, or equal to the weight of a shilling, it is called a *shilling van*, which is not rich; but if the van will cover or equal the weight of a crown-piece, it is good tin-stuff, and called a *crown van*. The shilling van, the tinners say, will produce one hundred avoirdupois weight of block or white tin; and the crown van will yield five hundred weight of block tin, for every hundred sacks in measure of the respective doles from which the sample or van was taken, and so in proportion, to the richest tin-stuff, called *scove*, which is reckoned at the rate of ten thousand of white tin-metal for every hundred sacks. But a better judgment may be formed from the measure of a wine half-pint, than from a handful, which is indeed accounted a half pint. When the tin, thus measured, is reduced clean, and to a proper size, by using a large shovel, and taking off the sized tin on another shovel, the van is dried in a shovel upon the fire, and then weighed by pennyweights and grains; and for every pennyweight and a half the van weighs, the produce will be one hundred weight of black tin for every hundred sacks of tin-stuff; and for three pennyweights, two hundred weight, &c. in the same proportion; and if it be tin worth ten for twenty, or one for two, then the tin-stuff is valued at five hundred weight of block or white tin for every hundred sacks: if it be worth twelve for twenty, the stuff is valued at six hundred weight of white tin a hundred; or if it be worth only eight for twenty, it is only valued at four hundred weight of white tin a hundred, &c. This *black* tin is rather of a liver colour, though called black in contradistinction from white tin, or the metal produced from this black ore: it is very heavy, and may in general be computed to hold one-half clean metal, and some of it will produce thirteen, or even fourteen parts in twenty; whence the mode of expressing so much white tin for twenty of black tin, *i. e.* eight for twenty, ten for twenty, twelve for twenty, &c. Thus, if the van of one hundred sacks of tin-stuff weighs six pennyweights, being four hundred weight of black tin at twelve for twenty, the white tin or metal must be two hundred weight one quarter sixteen pounds.

In this method of sampling, the tinners form a near conjecture of the quantity of white tin which their doles of tin-stuff will produce at the smelting-house, when it is dressed, and brought into black tin. But if the black tin is combined with any bad mixture, as of mock-lead, copper, or mundic, after the van is bruised fine and washed, they lay the shovel over the fire, and burn the black tin, stirring it continually, till it has done smoaking: they then wash it again on the shovel, and thus the heterogeneous matter, becoming light by being burnt, is carried off by the water: for when black tin is calcined or burnt, it still retains its specific gravity; but copper, lead, and other crude minerals, become much lighter by torrefaction, and are easily separated from the tin by water. In the dressing and management of tin by stamping, &c. there are obtained two sorts of black tin, *viz.* the crop and rough, or the crop and leavings of tin. The first is the prime tin: immediately separable from the baser parts by its superior weight and richness. The latter is that which is carried off, and mixed with the lighter earthy parts, by being under size, and, therefore, more easily carried off by the water.

The tin-stuff, after this previous preparation and adjustment, is carried to the stamping-mill, in order to be dressed or pounded.

This operation of pounding in the stamping-mill is essential to the complete separation of the ore from the matrix, through which it is disseminated. If full of slime, it is thrown into a pit, called a *buddle*, to wash away the earthy matter, and render the stamping more free, without choaking the grates. The ore is shovelled into a kind of sloping canal of timber, called the *pass*, whence it slides by its own weight, and the assistance of a small stream of water, into the box where the lifters work: the lifters are raised by a water-wheel, and are armed at the bottom with large masses of iron, weighing nearly two hundred weight each: these pound or stamp the ore sufficiently to enable it to pass through the holes of an iron grate fixed at one end of the box. To assist its pulverization, a rill of water keeps it constantly wet, and it is carried by a small gutter into the fire-pit, where it makes its first deposition; the lighter particles running forward with the water into the middle pit, then into a third, where what is called the *slime* settles. (See *Dressing of* ORES, and BUDDLE.) From these pits the ore is carried to the *keeve*, which is a large vat containing water; in which it is farther purified by an operation termed *packing*, and which consists in beating the upper part of the contents with mallets for some minutes, by which the lighter particles are kept suspended, whilst the tin-ore, from its great specific gravity, subsides. The waste is skimmed and laid by, to be again buddled, under the name of the *skimpings*. The tin is sifted through a copper-bottom sieve into another keeve of water, by which the gravelly waste still remaining is separated from the clean tin; and the tin that runs through the sieve, if it requires no farther buddling, may be cleaned by repeatedly tossing and packing it as before. If it be necessary to buddle it again after it is sifted, let it be buddled and distributed in three parts, *viz.* the crop or purest, the crease or next in purity, and the hind-crease or tail, which is the most impure. The crop is to be cleansed by tossing, &c. and the crease must be buddled again, and out of this must be reserved as much as may be cleansed by tossing and packing. The remainder must be cleansed by an operation called *dill ughing*, from *dilleugh, to let go, or send away*. A dilleugher is a large fine hair-sieve, which the dresser holds in a keeve one-third full of water, into which the tin is thrown by a shovelful at a time, and which is shook so as to put the tin into motion: one side of this dilleugher is dipped in water, and raised again in such a manner, that the waste may run over, which is laid aside to mix with the skimpings, to make the samples of low value, called the *rough* (or *row*) tin. This usually undergoes another operation, in which, by a rill of water passing over the buddle in which it is placed, it is farther cleansed, and then dilleughed, so as to be fit to mix with the crop-tin.

Upon the same mechanical principle of separation, the tinner is capable of estimating the value of a sample of ore. For this purpose, the pounded tin-ore, or tin-stuff, as it is called, is placed on a shovel and washed under a stream, till the impure earthy parts are carried off by the water from its sides, when, by a particular and dexterous motion, not easily described, all the metallic particles are collected together on the fore-part of the shovel: this operation is called *vanning*, which we have already described.

When the tin-ore is contaminated with the different pyritous ores of copper, arsenic, and iron, it is first roasted in a burning-house, and then washed in water, by which means the tin, which is heavy, is easily separated.

By this process, as at present conducted in Cornwall, a considerable quantity of copper is lost; for being converted into sulphate of copper, which is soluble in water, it is lost by washing: whereas, if the roasted ore were suffered to remain in a close pit for a few days, and the water drawn

off into another pit, the copper might be ſeparated by iron in a metallic ſtate.

The leavings of tin, conſiſting of the ſlime and tails, *i. e.* of tin-mud and tin-gravel, are dreſſed by a particular kind of apparatus, for the conſtruction and uſe of which, we muſt refer to Pryce's Min. Corn. p. 226, &c.

Each ſtamping-mill, which has conſtant work and water, will employ one man and five boys; and one hundred ſacks are carried, ſtamped, and dreſſed, in the ſpace of a few days, at the average rate of about four-pence *per* ſack, or one guinea and a half *per* hundred.

When the tin-ore is dreſſed, it is divided into as many ſhares as there are lords and proprietors.

The next operation pertaining to tin-ore, or black tin, is that of *ſmelting* it. The Phœnicians, who traded to Cornwall for tin in the earlier ages, probably conducted this proceſs by digging a hole in the ground, and ſtrewing the ore on a charcoal fire, which perhaps was excited by a bellows. But having no idea of confining the fire, and directing its force on the ſubſtance to be ſmelted, they made no uſe of furnaces, either ſimple or reverberatory. Charcoal was long uſed in the operation of ſmelting, till at length neceſſity ſuggeſted the introduction of pit-coal; and in the ſecond year of queen Anne, a patent was granted for ſmelting black tin with foſſile coal in iron furnaces. The invention of reverberatory-furnaces built with brick, ſtone, ſand, lime, and clay, ſoon followed this diſcovery; the form of which, being ſimple, has admitted of little improvement to the preſent time. The charge for one of the tin ſmelting-furnaces is from five to ſix hundred weight of black tin, well mixed with a tenth or twelfth or eighth its weight of culm, which is a ſpecies of coal from South Wales, that is very free from ſulphur. The furnace is charged through a hole in its ſide with a ſhovel, and the tin levelled over the bottom with an iron rake or paddle. The apertures are then cloſed, and the fire raiſed to a very great ſtrength, in which ſtate it is left for four or five hours, when the door is taken off, and the whole charge well ſtirred together. The ſtate of the metal is examined, and more culm thrown in if neceſſary; the furnace is again cloſed, and the fire kept up till the end of about ſix hours from its receiving the charge; when it is again examined, and if proper, it is then tapped, and the metal let out into a fixed baſon made of clay, and large enough to hold ſomewhat more than the metal of the charge. The ſcoria in the bottom of the furnace is raked out at the mouth into a ſmall pit made for this purpoſe, where it generally forms itſelf into a cake. When cold, it is carried to the ſtamping-mill, in order to ſeparate the globules of melted tin diſſeminated through the ſcoria or ſlag. This, being broke by hammers to the ſize of gooſe-eggs, is put into the firſt ſtamping-mill, and paſſed through ſmall iron bars; by which means the *pillion* (for ſo all tin recovered out of the ſlags is called) of the larger ſize is taken out and prevented from waſte by too much ſtamping. The refuſe of this firſt ſtamping is put into other ſtamping-mills of a ſecond, third, or even fourth ſize. Of the pillion, ſeparated from the ſcoria, all the rough or grainy parts are conſidered as metals, and refined accordingly, by being ſmelted without any flux, and the produce of this ſmelting refined, with the tin firſt tapped.

The tin in the baſon, or float (as it is called), as ſoon as it comes down to a moderate heat, is laded out into the moulds, in ſlabs or pigs of about three-fourths of a hundred weight.

The method of ſmelting in Saxony and Bohemia, does not differ greatly from that practiſed in Cornwall. When the ore has been roaſted it is waſhed upon tables, to ſeparate the oxyd of iron and the oxyd of copper, which are lighter than tin-ore. At Alt-Saint-John, the oxyd of tin is mixed with the black oxyd of iron: this is ſeparated by a powerful magnet, which is drawn over the table. That the powdered oxyd of tin may not be blown away by the blaſt of the furnace, it is previouſly moiſtened with water; but as the flame always carries away a part of the ore, a chamber is conſtructed about the middle of the chimney, made of wood lined with clay, where the powdered ore that has been driven up by the flame is depoſited.

The next proceſs is that of *refining*. The furnace having, by the ſide of the ſmall float now deſcribed, a larger one capable of holding twenty, or more blocks, is for this purpoſe ſuffered to cool to a certain degree, and then charged full with the ſlabs juſt mentioned, the tap-hole being kept open, ſo that as the tin melts in this moderate fire, it makes its exit through it into the float; where, while running out, it is frequently ſtirred and toſſed by a ladleful at a time held arm-high, letting it fall in a ſtream into the maſs of metal, when the ſcum which ariſes is taken off. While the metal already put into the furnace is melting, more is added, ſo as to be juſt enough to fill the float with good tin: and this, after being toſſed and ſkimmed as before, and ſuffered to cool to a proper temper, is carried in iron ladles to moulds holding generally ſomewhat above three hundred weight (then denominated *block-tin*), where they are marked as the ſmelters chuſe with their houſe mark, which may be a pelican, plume of feathers, ſtag, or horſe, by laying braſs or iron ſtamps, in the face of the blocks while the tin is in a fluid ſtate, and yet cool enough to ſuſtain the ſtamping iron. The blocks are then ready to be weighed, numbered, and ſent to the neareſt coinage town to be coined. The privileged towns for coinage of tin, were anciently Liſkeard, Loſtwithiel, Truro, and Helſton: but ſoon after the Reſtoration, Penzance was added to the number; in which laſt place there is every quarter more tin coined than in the towns of Liſkeard, Loſtwithiel, and Helſton, for a whole year. When the tin is brought to be coined, the aſſay-maſter's deputy aſſays it by cutting off with a chiſſel and hammer a piece of one of the lower corners of the block, about a pound weight, partly by cutting and partly by breaking, in order to prove the roughneſs and firmneſs of the metal. If it is a pure good tin, the face of the block is ſtamped with the duchy ſeal, which ſtamp is a permit for the owner to ſell, and at the ſame time an aſſurance that the tin ſo marked has been examined and found merchantable. The ſtamping of this impreſſion by a hammer is *coining* the tin, and the man who does it is called the *hammerman*. The duchy ſeal is argent, a lion rampant gules, crowned or, within a border garniſhed with bezants.

The droſſy part remaining in the furnace is by an increaſing fire wholly melted, which is then tapped into the ſmall float, where the tin ſubſiding, and the droſs riſing to the top, the latter is taken off, and the tin laded into ſmall ſlabs, as at firſt, to be again refined. The tin that remains in and about the ſcoria and droſs of the laſt tappings, &c. is recovered by repeated ſmeltings, till at laſt, being almoſt entirely drained of that metal, they become what the workmen generally call *hard heads*, and eſteemed of no farther value.

M. Groſſe, in the Memoirs of the Academy of Sciences of Paris, has delivered a method he had invented of ſeparating tin from lead or ſilver. Having tried an experiment on the ſcoriæ of metal, which contained with the tin a large quantity of ſilver, it ſeemed to him that one great ſtep toward the ſeparation of the ſilver, was the haſtening of the calcination of the tin, and with this view he tried a mixture

of charcoal, faltpetre, and earth, which he put together into the coppel with the fcoriæ. It is eafy to fee that a detonation would happen from this, and this muft greatly add to the force of the fire, in acting upon the fcoriæ, while the ferruginous matter well known to be contained in the charcoal mixed itfelf with the tin, and muft greatly accelerate its calcination, divide its parts, and give the fire a new action over it. The confequence of this perfectly anfwered expectation, and recovered a large quantity of filver from the fcoriæ, in which the tin had before held it firmly imbodied; repeated experiments proved the truth of this obfervation, and it was found to be eafy by this means at any time to feparate filver from tin, or to purify filver without lofs, by means of lead in which tin has accidentally been imbodied.

The fcoriæ in which tin is mixed with filver, are compofed of tin half calcined, and run into an opaque vitrified fubftance, which forms a fort of net-work, in which the filver is confined in extremely fmall particles. If this is thrown into aqua fortis, the whole is diffolved: but then it requires a very ftrong fire to make the tin lofe its metallic form; finally, if the whole is finely powdered, and then put into this menftruum, the filver only is taken up or diffolved, the tin remaining untouched at the bottom of the veffel.

The fame gentleman found alfo a method of feparating tin from filver, by means of corrofive fublimate of mercury. To conceive the manner in which this feparation is effected, a piece of fine tin need only be caft into a folution of fublimate; in which cafe the acid of the fea-falt is feen to leave the mercury in order to fix upon the tin.

And, according to the fame principle, if fublimate corrofive be added to a mixture of tin and filver, the fame effect is produced, the acid affixes itfelf to the tin, and makes with it a butyrum joviale or butter of tin, the mercury becomes diffipated in the mean time by the action of the fire, and the filver remains pure and alone; but in this experim nt, if too much corrofive fublimate be added, there is danger of lofing fome of the filver; fince the abundant acid will prey upon and carry off a part of that metal, making a fort of luna cornea which diffipates itfelf in the air, or if the operation be performed in a clofe veffel, a butyrum lunare.

Gold may alfo be purified from tin in this manner, and in this there is no rifk of lofs, fince the acid which takes up the tin has not the leaft power over that metal: in all thefe proceffes, however, the operator muft avoid the fumes iffuing from the crucible, for they are very dangerous.

Thefe methods of feparating of tin from filver are very certain and infallible, but they are too expenfive to be employed in common, and in larger works.

The feparating of tin from lead to be employed in the refining of filver is a matter of great importance; and this may be done in the following manner: melt the lead, and when in fufion throw into it a quantity of filings of iron, then increafe the fire to a confiderable degree, and the furface of the metal will be covered with a fort of fcum, which is no other than the iron and tin. At this time there fhould be a little alkali falt thrown in,' and by this means the fcoriæ readily feparate themfelves, and the pure lead remains in form of a regulus at the bottom. The fame method may be ufed to feparate tin from filver in the larger way, but it will be neceffary for this purpofe to add fome lead, fince otherwife the fufion will be very flow and difficult, and the tin will calcine without feparating from the filver. This is a very eafy and very cheap method, and will obviate moft of the mifchiefs which happen to the refiners, of which they would have much lefs frequent reafon to complain, if they nicely examined the lead they were to employ. But if gold or filver be mixed with tin, the fhorteft method in fmall quantities is to calcine the whole very brifkly, and in order to complete the vitrification and feparation of the tin, to caft in a little glafs of lead, which will immediately join itfelf with it and carry it off from the mafs.

It may feem fingular that iron being one of the hardeft of the metals to melt, and tin being of all the eafieft, they fhould fo readily and eafily unite in thefe experiments; but this feems to be the refult of one of thofe natural and unexpected alliances which accident frequently difcovers to us in bodies. There is one conjecture, however, that may be worthy a place in this refearch, which is, that all tin-ore contains a quantity of arfenic; and it is well known that iron very readily mixes with arfenic, and is employed to feparate the arfenic from other ores, and a regulus may be formed of arfenic and iron. It is eafy to fuppofe that tin is, in its metalline form, not wholly divefted of the arfenic it contained when in the ore; and if this be allowed, it is no wonder that the two metals are eafily brought together by the mediation of that principle. Memoirs Acad. Scienc. Par. 1737.

Mr. Cramer gives the practical rules of feparating filver from tin, thus: Divide one centner of tin into two equal parts; put each of thefe into a feparate teft, and add to each fixteen centners of granulated lead, and one of copper; put the whole under the muffle, and make a very ftrong fire; the tin will be calcined immediately, and will fwim upon the lead. Then diminifh the fire a little, till the afhes of the tin that fwim upon the furface do no longer fparkle: when you fee this, add with a ladle two centners of glafs of lead to each teft, in fuch a manner that it may be fpread wide over the whole furface of the rejected calx; the calx will then change its form of powder into that of glafs; then increafe the fire to its higheft degree, ftir up the whole with an iron rod made warm; and when the fcorification is perfected, pour out the glafs into a mould; the fcoriæ being feparated, put both the regulufes into two coppels well heated; and into a third put fixteen centners of lead, and one of the fame copper ufed in the procefs: examine all thefe beads after the coppelling is over; if the two firft weigh exactly alike, it is a proof the procefs has been well performed; and fubtracting the weight of the bead, feparated from the third pan, from the joint weight of the other two, the remainder is the weight of the pure filver contained in the quantity of tin which was examined. Cramer's Art of Affaying, p. 228.

Tin is found in Europe, Afia, and America, but has not hitherto been difcovered in the continent of Africa. This metal is much lefs generally diffeminated than gold, filver, iron, copper, or lead; but where it occurs, it is moft frequently in large quantities. In Afia it is found on the coaft of Sumatra, and in Siam and Pegu. It is principally imported into our Indian poffeffions from Queda, Junkfeilon, Tavai in Lower Siam, and the ifland of Banca. The tin-mines of Banca are faid to be of great extent; and Mr. Ellmore informs us, that no lefs than from forty to fixty thoufand peculs of tin are furnifhed by thefe mines annually. Tin is faid alfo to be found at a place five days' journey from Nankin in China. The Indian tin was known to the ancients. Diodorus Siculus mentions it among the productions of India. Tin-ftone is found in Mexico in the ftate of ftream-tin, and is procured from alluvial depofitions by wafhing. It is alfo faid to occur in Chili.

Tin-ore occurs in Saxony and Bohemia in beds, and diffeminated in granite rocks; it is found alfo in veins in rocks of granite, gneifs, and mica-flate. Alluvial depofitions of tin are alfo met with in thefe diftricts. The mines fometimes confift of a mafs of ore formed by the junction of a multitude

of ſmall veins which paſs through the rocks in different directions. Theſe veins alſo contain topazes. Brongniart Traité Elementaire.

Tin is found near Monterey, in the province of Gallicia in Spain, in veins which traverſe granite and mica-ſlate. This ore has recently been diſcovered in ſmall quantities in grains and cryſtals, in a rock of granite at Puy les Vignes, in the vicinity of St. Leonhard, in the deparment of Haute-Vienne in France. It occurs in veins with wolfram, arſenical pyrites, and martial arſeniate of copper.

The moſt conſiderable repoſitory of tin-ore in Europe is that of Cornwall. The greateſt part of the tin conſumed in Europe is procured from thence; and Camden even ſuppoſes this abundance of tin in Cornwall and Devonſhire, to have given the original denomination *Britain* to the whole kingdom. In the Syriac language, *varatanac*, or *baratanac*, ſignifies *land of tin;* from which Bochart derives the name *Britain*. It occurs in Cornwall, both in veins and alluvial depoſitions, in various parts of the county. Alluvial depoſitions of this ore are alſo met with on Dart-moor, in Devonſhire. The veins which contain tin interſect both granite and ſlate rocks; the latter are provincially called *killas*. Theſe veins vary in width, and ſometimes contain large maſſes of the ore. One block was raiſed from the mine called Polberrow, in St. Agnes, which weighed more than twelve hundred pounds, and produced more than half that weight of pure metal. Tin-ſtone generally occupies the upper part of veins, and is ſucceeded by copper-ore; but there are inſtances of tin occurring at the depth of two hundred fathoms. Different modifications of the forms of the cryſtals are peculiar to certain veins. Cryſtals of tin-ſtone are alſo diſſeminated in ſome of the granite rocks in the vicinity of veins: the cryſtals appear to occupy the place of mica. Where the tin-ſtone is diſſeminated in ſlate, it is generally in ſmall ſtrings or minute veins. See MINE and VEINS.

The workmen diſtinguiſh ſeveral kinds of tin; as *moor-tin*, which is the beſt ſort, a fool of which weighs eighty pounds; and *mine-tin*, which is the next, the fool of it weighing about fifty-two or fifty pounds. The tin got from the ſoft, gravelly earth, they call *pryan-tin*, to diſtinguiſh it from that obtained from the ſtones, which is better by almoſt half. See STREAM-*Tin Ore*.

Grain-tin denotes the ore of tin that is ſometimes dug very rich in the form of grains or pebbles, or elſe in larger pieces, compoſed of many ſuch diſtinct grains, united in one maſs, always of a black or dark roſin colour, pointed like diamonds. Grain-tin is alſo uſed to ſignify the pureſt and fineſt block or white tin, ſmelted with charcoal in the blaſt or blowing-houſe furnace, which never had any brood or foreign mixture in the mine: whereas the mine-tin is uſually corrupted with ſome portion of mundic, or other mineral, and is always ſmelted with a bituminous fire, which communicates a harſh ſulphurous quality to the metal. Grain-tin is peculiarly produced from ſtream-work, and is worth ſeveral ſhillings *per* hundred more than mine-tin. See STREAMING.

See on this article Macquer's Chem. Dict. art. *Tin;* and Pryce's Mineralogia Cornubienſis, fol. 1778.

There is a curioſity in the Corniſh mines, which is this: that in digging at the depth of forty or fifty fathoms, they frequently meet with large timber, ſtill entire.

Childrey, in his Natural Hiſtory, goes back as far as the deluge to place them there; but, without having recourſe to ſo great antiquity, they who believe that the mines, when exhauſted of their ore, or mineral matter, renew and fill again in courſe of time, will ſoon ſolve the difficulty, by ſuppoſing that, in the firſt working of theſe mines, theſe timbers had been let down to ſerve as props and pillars.

But there are other people who will think this renewal of the mines itſelf a difficulty as great as the former. However, what the former author adds, *viz*. that in ſome places in the mines they likewiſe find pick-axes, &c. with wooden ſhafts, as alſo braſs nails, and that even a medal of Domitian has been found in one, ſeems to countenance the opinion.

For the uſe of tin in the compoſition of pewter, ſee PEWTER.

TIN-*Trade of Britain*. That tin was procured from Britain in a very early age, appears probable from the concurrent teſtimony of the moſt ancient hiſtorians. The Phœnicians are ſaid by Strabo to have paſſed the pillars of Hercules, now the ſtraits of Gibraltar, about twelve hundred years before Chriſt. At what preciſe period they diſcovered the Caſſiterides, or Tin iſlands, is unknown, nor is their exact ſituation determined; but it is generally believed that the Scilly iſlands, and the weſtern part of Britain, were the places from whence theſe early navigators procured the tin which they exported to other countries. The Phœnicians were extremely anxious to conceal from the reſt of the world the true ſituation of the Caſſiterides. Herodotus, who wrote about four hundred and fifty years before Chriſt, could not learn where theſe iſlands were ſituated; but he ſuppoſed that tin, like amber, was brought from the remoteſt parts of Europe. Strabo relates, that the captain of a Phœnician veſſel returning from Britain ſeeing himſelf purſued by a Roman galley, choſe rather to run his veſſel among the rocks, that the Romans might experience the like fate, than be the means of diſcovering ſo valuable a commerce to the enemies of his country. The captain having eſcaped from the wreck, claimed from his country compenſation for the loſs of his veſſel and the cargo; and it is ſaid he was paid from the public treaſury the amount of his claims. By theſe precautions, the Phœnicians are ſaid to have enjoyed a profitable trade to theſe iſlands for about three hundred years. The ſecret was at length diſcovered, and the Greeks, Gauls, and Romans, came in ſucceſſively for a ſhare of this trade. The Phocean Greeks eſtabliſhed a colony at Marſeilles five hundred and forty years before Chriſt; and after the deſtruction of Carthage, carried on this commerce: they endeavoured to conceal from the Romans their knowledge of the Britiſh iſles; for on being queſtioned by Scipio reſpecting the ſituation and extent of thoſe iſles from whence the tin was brought, they declared that they were entirely unknown to them. The Phœnicians, in their voyage to Britain, are ſaid to have ſailed from Cadiz to the harbour of the Artabici, near Cape Finiſterre, from whence, after four days' ſail, they arrived in Britain. Strabo relates, that Publius Lucius Craſſus having made fruitleſs attempts to diſcover whence the tin was brought, at length ſucceeded, and arrived in Britain. It is uncertain when this Craſſus lived, and even who he was, there being two of this name; the father, who was proconſul of Spain, and the ſon, who had a command under Cæſar in Gaul.

Diodorus Siculus, who wrote during the time of Auguſtus, appears, from the quotation which we ſhall ſubſequently give, to have been well acquainted with the tin-trade of Britain at that period. There cannot be a doubt, that from the conqueſt of Britain by the Romans, to the decline of their empire in the Weſt, they enjoyed the undiſturbed poſſeſſion of the Britiſh tin-trade.

What the ancient method was of preparing tin for the furnace we cannot learn, ſays Dr. Borlaſe. Polybius the hiſtorian is ſaid to have deſcribed it; and that work is com-

mended by Strabo, but now loft. The fhort defcription of the tin-trade given by Diodorus Siculus deferves particular attention. "Thefe men (the tinners) manufacture the tin by working the grounds which produce it with much fkill. For though the land is rocky, it has foft veins running through it, in which the tinners find the treafure, which they extract, melt, and purify. Then fhaping it by moulds into a cubical figure, they carry it off to a certain ifland lying near the Britifh fhore, which they call Ictis; for at the recefs of the fea between the ifland and the main land, the paffage being dry, the tinners embrace the opportunity, and carry the tin over in carts to the Ictis or Port; for it muft be obferved, that the iflands which lie between the continent and Britain have this peculiarity, that when the tide is full they are real iflands, but when the fea retires they are fo many *peninfulæ*. From this ifland the merchants bring the tin of the natives, and export it into Gaul; and finally through Gaul, by a journey of about thirty days, to the mouth of the Rhone:" lib. 4. Pofidonius, as quoted by Strabo, fays the port to which tin was brought in the fouth of France was Marfeilles.

To what ufes the nations of antiquity applied all the tin which they obtained with fo much labour from Britain, is not precifely known. The Phœnicians were celebrated for their fkill in the art of dyeing; and the Tyrian purple, which was either a bright crimfon or a fcarlet, was held in the higheft eftimation; hence it has been conjectured, with much probability, that the Phœnicians were acquainted with the ufe of the folution of tin in the preparation of that colour. In the modern art of dyeing fcarlet or crimfon, the folution of tin in the nitro-muriatic acid is effentially neceffary to communicate thofe colours to woollen cloths or ftuffs, a practice which is probably derived from the ancient manufactures of the Eaft.

The mirrors of the civilized nations of antiquity were made of a compofition of copper and tin. The moft ancient account that we have of thefe mirrors is that in Exodus, chap. xxxviii. 8. "And he made the laver of brafs (a mixture of copper and tin), and the foot of brafs of the mirrors of the women." The Jewifh women probably received thefe mirrors from the Egyptians when they left the country; for it was the cuftom of the Egyptians to carry a mirror in their left hand, when they went to their temples. Cyril de Ado.

Pliny fays that the beft fpecula were anciently made at Brundufium of copper and tin. The metallic mixture of tin and copper, for rendering the latter metal white, is mentioned by Ariftotle. (De Mirab.) This compofition is ftill in ufe for the fpecula of reflecting telefcopes. (See SPECULUM.) The ancients alfo made ufe of an alloy of tin with copper and lead for pot-metal. In the time of Pliny, pot-metal, *ollaria temperatura*, was made of two pounds of lead, and an equal quantity of tin, mixed with one hundred pounds of copper. From the fame writer we learn, that the bronze of which the Romans made their ftatues, and the plates on which they engraved their infcriptions, was compofed of one hundred pounds of copper, mixed with twelve pounds and a half of an alloy made of equal parts of lead and tin. He informs us alfo that tin, *plumbum album*, was employed in coating or tinning copper veffels, to render them more wholefome; and it appears that the Romans not only ufed pure tin, but the fame mixture of tin and lead which fome of our workmen ufe at this time in tinning of veffels. A mixture of equal parts of tin and lead they called *argentarium;* a mixture of two parts of lead and one of tin they called *tertiarium;* and with two parts of tin and one of lead, they tinned whatever veffels they thought fit. (Watfon's Chemical Effays, vol. iv.) In the manufacture of arms, the ancients ufed an alloy of tin with copper, their brafs being a compofition of thefe metals; but by what method they were enabled to communicate to it the neceffary degree of hardnefs is unknown.

What was the relative value of tin, compared with that of gold and filver, as eftimated by the Phœnicians, the Greeks, or the Romans, is uncertain.

The procefs of extracting tin from its ores was probably very imperfect, and remained fo in this country to the time of Elizabeth, when Carew informs us that fir Francis Godolphin introduced great improvements in the tin-works.

The reverberatory-furnace appears, from Dr. Borlafe, to have been introduced into Cornwall about the beginning of the laft century; and about the fame time the introduction of pit-coal became general, the wood of the country having been nearly exhaufted. Sir Bevil Granville had previoufly made many experiments for melting tin with pit-coal, but without fuccefs, when the ore was fmelted at the blowing-houfes by large bellows worked by a water-wheel.

Whether the Phœnicians or the Greeks interefted themfelves in the management of the tin-mines, or whether they were fimply merchants purchafing and exporting the tin, is uncertain. It appears, however, by the paffage quoted from Diodorus Siculus, that the veins of tin-ore were worked as mines; though it has been, and is ftill generally believed, that ftream-tin was the only ore worked by the ancients. From the teftimony of Strabo, Pliny, and others, the Romans not only traded to Britain for tin, but improved the art of mining in Cornwall. The Romans being the conquerors, and the Britifh under them having probably little or no property, they were the working miners, but under what regulations is uncertain. The Saxons did not obtain poffeffion of Cornwall till the reign of Athelftan, and neither they nor the Danes appear to have directed their attention to the mines. After the Norman conqueft, the working of mines is faid to have yielded great profit. In the time of king John, however, the right of working tin being as yet, fays Borlafe, wholly in the king, as earl of Cornwall, the property of the miners was precarious and unfettled, and all the tin that was raifed was engroffed and managed by the Jews. The *tin-farm* of Cornwall at this time amounted to no more than one hundred marks, according to which valuation, the bifhop of Exeter received then, and ftill receives from the duke of Cornwall, the annual fum of 6*l.* 13*s.* 4*d.*, fo low were the tin profits then in Cornwall; whereas in Devonfhire, the tin was then farmed at 100*l.* yearly. King John, fenfible of the languifhing ftate of the mines, granted the county of Cornwall fome privileges, and is faid to have alfo granted a charter to the tinners.

In the time of Henry III. the tin-mines of Spain, which had been worked by the Moors, were ftopped, and Cornwall had all the trade of Europe for tin. In the eighteenth year of Edward I., the Jews being banifhed the kingdom, the mines were again neglected for want of proper encouragement to labour, and fecurity to enjoy and difpofe of the products. In confequence of a petition from fome Cornifh gentlemen to Edmund, earl of Cornwall, a charter was obtained with more explicit grants of privileges of keeping courts of judicature, and managing and deciding ftannary caufes. About this time, fays Borlafe, it appears that the rights of bounding or dividing tin grounds into feparate portions, for encouraging the fearch for tin, were more regularly adjufted, and various laws introduced for the protection of the miner.

In the thirty-third year of Edward I. the above charter ſeems to have been confirmed, and the tinners of Cornwall were made a diſtinct body from thoſe of Devonſhire, before which time the tinners of both counties were accuſtomed to meet on Hingſton-Hill every ſeventh or eighth year, to concert the common intereſt of both parties. Two coinages of tin yearly were alſo granted by this charter, and the tinners had the liberty of ſelling their own tin, unleſs the king inſiſted on buying it himſelf. Other laws and regulations for the encouragement and protection of the miners, were paſſed in the reigns of Edward III., Henry VII., and Elizabeth. The mines having been much neglected during the reign of Mary, Elizabeth invited German miners into the country, and great encouragement was given to mining operations in Cornwall, and various parts of England. The quantity of tin procured annually in the ſucceeding reigns of James I. and Charles, amounted to ſixteen hundred tons. During, and for ſome time after the civil wars, the tin-trade declined, but revived again in the reign of George I., and has ſince been increaſing. For an account of the annual products of the tin-mines of Cornwall and Devonſhire, ſee the article MINE.

All the tranſactions connected with the tin-mines are under the controul of the ſtannary laws: courts are held every ſix months, and they decide by juries of ſix perſons, with a progreſſive appeal to the lord warden and lords of the duke of Cornwall's council. By whatever method or accident a vein is diſcovered, permiſſion of the proprietor muſt be obtained before any operations can be commenced, except in the caſe of ſuch tin-mines as are anciently embounded according to the proviſion of the ſtannary laws. (See STANNARY COURTS.) The owner of the ſoil is technically called the *lord*, whoſe ſhare (which is called his *diſh*) is generally one-ſixth or one-eighth of the ore. The duke of Cornwall receives a duty of four ſhillings *per* hundred weight of tin, which is taken when the tin is aſſayed and licenſed: this proceſs is called the *coinage*, from the French word *coin*, a corner. A corner is chipped off each block at the office, and if it be found ſufficiently pure, the blocks are ſtamped with the arms of the duke. The annual revenue of the tin is about 10,000*l.*; the average annual amount being about 3200 tons, and the value about 120*l.* *per* ton. The mode of aſſay is obviouſly rude and imperfect; and we have heard that foreigners have recently complained that the Britiſh tin was not ſo pure as that obtained from the Eaſt. But whatever be the purity of Britiſh tin, there can be no doubt that it is greatly adulterated on the continent. It is ſaid that every tin-founder in Holland has Engliſh ſtamps, and be the quality of the tin what it may, the inſcription makes it paſs for Engliſh. The metal with which Britiſh tin is adulterated on the continent is lead, which being five times cheaper, and when mixed in ſmall quantities not eaſily detected, the temptation for ſuch fraud is great. It is not true, as aſſerted by ſome foreign writers of reſpectability, that Britiſh tin is purpoſely alloyed with certain portions of copper and lead before it is exported from Cornwall. The ores of tin, in the tin-mines of Cornwall, are ſo intimately aſſociated with portions of copper-ore, lead-ore, arſenical pyrites, and other metals, of which a ſmall mixture will remain in the block-tin, and can only be ſeparated by ſubſequent refining, that any conſiderable portion of alloy may be detected by the increaſe of ſpecific gravity. Grain-tin, which is the pureſt tin of commerce, is ſmelted from the fineſt ore by a charcoal fire: the common block-tin is ſmelted with pit-coal or culm, as before ſtated. Grain-tin is uſed for various purpoſes in the arts, where tin of the pureſt quality is required.

Long as the tin-mines of Cornwall have been worked, they ſtill continue to ſupply in abundance this uſeful metal; but from the greater extent of the preſent works, and from the circumſtance of tin always occupying the upper part of the vein, we may infer that the tin-mines of that county will be exhauſted at no very diſtant period. At preſent, the principal part of the tin is obtained from the weſtern extremity of the county; but when the tin-mines in that diſtrict are worked out, we may conſider the tin-trade of Cornwall as nearly extinct. The granitic range of Dartmoor, in Devonſhire, has been leſs explored than Cornwall; but there is reaſon to believe that the metallic repoſitories of tin and copper which it contains will furniſh an ample field for the induſtry of future adventurers, and a failure in the ſupply from Cornwall would greatly enhance the price of this metal, and give increaſed ſpirit to mining ſpeculations.

TIN, in *Chemiſtry* and the *Arts*. The colour of tin is white, like that of ſilver: it has a ſenſible taſte, and when rubbed, emits a peculiar ſmell: its hardneſs is greater than that of lead, and leſs than that of zinc: its ſpecific gravity is ſtated by Briſſon to be 7.291, and it is ſaid to become a little greater by hammering: it is very malleable, and may be beaten into very thin leaves. *Tin-foil*, as it is termed, is uſually about $\frac{1}{1000}$th of an inch in thickneſs; but this is by no means the utmoſt degree of thinneſs which it will bear. Its ductility and tenacity are rather low: a tin wire, $\frac{1}{16}$th of an inch in diameter, is ſtated by Muſchenbroeck (as quoted by Dr. Thomſon) to be capable of ſupporting a weight of 31 lbs. only, without breaking. Tin may be eaſily bent, and when bent, produces a peculiar crackling noiſe: it fuſes at about 442° of Fahrenheit's ſcale, but will bear a moſt intenſe heat before it is volatilized. On being expoſed to the atmoſphere, its ſurface becomes ſlightly tarniſhed, but it undergoes no other change. When kept under cold water it undergoes no change; but red-hot tin, expoſed to the vapour of water, decompoſes it, an oxyd of tin is formed, and hydrogen gas is evolved. Expoſed to the action of the air in a melted ſtate, it quickly becomes covered with a greyiſh powder, or oxyd; and if the heat is very violent, it is ſtated to take fire, and to burn with a pale white light.

Tin unites with oxygen in two proportions, as has been lately proved by Gay Luſſac, in oppoſition to Berzelius, who concluded from his experiments that there were three oxyds of tin. (See Annal. de Chimie et Phyſ. vol. i. p. 40.) The firſt oxyd, or protoxyd, of tin, conſiſts of about

Tin	-	-	100.
Oxygen	-	-	13.6

The ſecond, or peroxyd, of about

Tin	-	-	100.
Oxygen	-	-	27.2

This gives the weight of the atom 7.352. Dr. Thomſon is inclined to conſider it as 7.375; but it perhaps will be found hereafter either 7.25 or 7.5. The firſt of theſe oxyds may be formed by diſſolving tin in muriatic acid, either by means of heat, or by adding occaſionally a little nitric acid: when diſſolved, add to it a ſolution of potaſh; a white precipitate falls, which is partly taken up again; but the remainder, on ſtanding, aſſumes a dark grey colour, and even a metallic luſtre; and on being heated to whiteneſs, is pure protoxyd of tin. The peroxyd may be formed by

boiling the protoxyd in dilute nitric acid, drying by evaporation, and heating to rednefs.

Tin forms likewife two combinations with chlorine. When tin is burnt in chlorine, a very volatile clear liquor is formed, a non-conductor of electricity, and which, when mixed with a little water, becomes a folid cryftalline fubftance, a true muriate of tin, containing the peroxyd of tin. This compound has been called the *fmoking liquor of Libavius*, from its difcoverer, who formed it by diftilling together amalgam of tin and corrofive fublimate. According to the experiments of Dr. John Davy, it confifts of two atoms or proportions of chlorine united to one of tin; or of about

Tin	-	100.
Chlorine	-	121.82

Prochloride of tin, firft defcribed by Dr. J. Davy, is a grey, femi-tranfparent, cryftalline folid, and may be formed by heating together amalgam of tin and calomel. According to the fame chemift, it confifts of one atom or proportion of chlorine united to one of tin; or of about

Tin	100.
Chlorine	60.72

Tin combines readily with fulphur and phofphorus, but not with hydrogen, azote, carbon, or boron.

There are two fulphurets of tin; the firft may be formed by fufing tin and fulphur together: it is of a blueifh colour, and lamellated ftructure; and from the experiments of Dr. J. Davy, confifts of one proportion of tin united to one of fulphur. The other fulphuret of tin is made by heating together the peroxyd of tin and fulphur. It is of a beautiful gold colour, and appears in fine flakes. It was formerly called *aurum mufivum*, and various complicated proceffes given for forming it. Pelletier and Prouft inveftigated its nature, and concluded it to be a compound of oxyd of tin and fulphur; but Dr. Davy has fhewn that this is not the cafe, and that it confifts merely of one proportion of metallic tin united to one proportion of fulphur.

The phofphuret of tin may be formed by heating the two fubftances together. Only one phofphuret is known: it has a metallic appearance, and is fo foft that it may be cut with a knife. When gently heated in the air, the phofphorus takes fire. According to the experiments of fir H. Davy, it contains about 17 *per cent.* of phofphorus, and confifts therefore of one atom or proportion of phofphorus united to one of tin.

Tin combines with moft of the metals, and fome of its alloys are much employed.

Its alloys with the metals of the fixed alkalies fpeedily tarnifh in the air, and effervefce in water.

It readily unites with gold by fufion, and was formerly fuppofed to have the property of rendering this metal brittle; but this has been more recently denied. An alloy of 11 gold and 1 of tin, was found by Mr. Hatchett to have a pale whitifh colour, brittle when thick, but when cut thin, capable of being bent eafily. Its fracture was fine-grained, and of an earthy appearance. Mr. Alchorne found, that gold alloyed with no more than $\frac{1}{17}$th of tin, retains its ductility fufficiently to be rolled and ftamped in the ufual manner. But Mr. Tillet fhewed, that when heated to rednefs, the tin melts, and the alloy falls to pieces.

Its alloys with platina, according to Dr. Lewis, are brittle and dark-coloured, when the two metals are in equal proportions. The alloys of tin and filver are very hard and brittle. The alloys, or rather amalgams, of tin and mercury differ in hardnefs, according to the proportions in which the two metals are mixed: three parts of mercury and one of tin form an amalgam which cryftallizes in cubes, or, according to Sage, in the form of brilliant fquare plates, thin towards the edges. Tin readily combines with copper, and forms alloys exceedingly ufeful for a variety of purpofes, as will be briefly noticed when we fpeak of the ufes of this metal. Tin does not readily combine with iron, but their union may be effected by fufing them together in clofe veffels: it combines with zinc by fufion, and the alloy is harder than zinc, and ftronger than tin: with lead it readily unites in all proportions, and the lead by the addition becomes confiderably harder.

The oxyds of tin are capable of combining with the alkalies, and of forming with them peculiar compounds.

Salts of Tin.—Tin is oxydated and diffolved by many of the acids, and forms falts, differing in their nature according to the degree of oxydizement of the metal.

Nitrates of Tin.—Concentrated nitric acid (fpecific gravity 1.48) poured on tin, exerts but little action upon it; but if a little water be added, a violent action is exerted, and peroxyd of tin is formed, which feparates in the form of a white powder, this oxyd being apparently incapable of combining with nitric acid: in this cafe, both the acid and the water are decompofed, and nitrate of ammonia is formed; but if the acid be diluted, and care be taken to moderate its action upon the metal, the water only is chiefly decompofed, and the protoxyd of tin is formed, which combining with the nitric acid, forms a folution of a yellow colour, which is a real nitrate of tin. Still, however, a little nitrate of ammonia is formed, and the nitrate of tin itfelf is not permanent, the metal continuing to pafs to the ftate of peroxyd, and gradually feparating. The fame change is produced by heating the folution, a precipitate being depofited, which, however, is partly fubnitrate of tin.

Muriates of Tin.—We have already fpoken of the chlorides, or compounds of tin with chlorine. Now if water be added to thefe chlorides, they are converted into muriates of tin. The muriate of tin, in which the metal is in the ftate of protoxyd, may be formed, however, by diffolving tin in about four times its weight of muriatic acid: hydrogen efcapes, and the folution has a brownifh-yellow colour, and yields, on evaporation, fmall needle-fhaped cryftals, foluble in water, and fomewhat deliquefcent. Water poured upon it in fmall quantity decompofes it, and converts it into a fubmuriate, which is precipitated, and a fuper-muriate, which remains in folution. A fimilar effect is produced by the alkalies, when not added in excefs. This muriate of tin, formed of the protoxyd, has a great tendency to combine with oxygen, and to pafs into the ftate of muriates with the peroxyd, and this property enables it to exert many curious efforts upon other metallic falts. Thus, for example, the red oxyd of mercury, the black oxyd of manganefe, the white oxyd of antimony, the oxyds of zinc and filver, are deprived of their oxygen by this falt, and reduced to the metallic ftate. The muriate of tin with the peroxyd of the metal may be formed as before mentioned. It is capable of cryftallizing, and poffeffes properties quite different from thofe of the muriate above defcribed. It is much ufed by dyers, who generally form it by diffolving tin in nitro-muriatic acid.

Sulphate of Tin.—Sulphuric acid, when cold, has little action on tin, but affifted by a moderate heat, it attracts oxygen from it; fulphurous acid gas is evolved, and a fulphate of tin is formed, which yields, when evaporated, fmall needle-formed cryftals. It is probable there are two

sulphates of tin, though their properties do not appear hitherto to have been distinctly defined.

The *phosphate*, *fluate*, and *borate of tin* may be formed by double decomposition, by adding solutions of their alkaline salts to a solution of muriate of tin. They are all insoluble compounds, and have been but imperfectly examined. No *carbonate of tin* appears to exist.

The other salts of tin are unimportant, and but little known. The *acetate* has been most investigated: it may be formed by boiling tin in acetic acid. The solution has a whitish colour, and yields crystals by evaporation. There appears, however, to be another *acetate*, (formed probably with the peroxyd of the metal,) that does not crystallize, but is capable of existing only, on evaporation, in the form of a gummy mass.

Uses of Tin and its Compounds.—Tin and its compounds are extensively used in the arts. We shall here briefly point out some of the more important operations in which they are concerned, referring our readers for further particulars to the different articles themselves. An amalgam of tin and mercury forms the metallic coat of glass mirrors. For the method of performing this operation, see the article SILVERING *of Mirrors*.

The compounds of tin with copper are very important. Of this alloy *cannons* are made, also *bell-metal*, *bronze*, and the *mirrors* or *specula of telescopes*. For these different purposes, the two metals are mixed in different proportions, which are pointed out more particularly under their respective articles.

Vessels of copper, especially for culinary purposes, are usually covered with a thin coating of tin, to prevent the copper from oxydating. (See the article TINNING.) Thin iron plates covered with this metal, form what is known by the name of *tin-plate;* which see.

The oxyd of tin, mixed with that of lead, forms *putty*, which is much used in polishing metals. See PUTTY and SPECULUM.

Tin alloyed with lead forms *solder;* which see.

Of the salts of tin, a solution of the *muriate*, or *dyers' liquor*, as it is termed, is used as a mordant in dyeing scarlet. See the articles DYEING, MORDANT, and RED.

The solution of tin in aqua regia, added to the tinctures of cochineal, of gum-lac, and of some other red tinctures, heightens the colour of these, and changes it from a crimson or purple to a vivid reddish-yellow, or fire-coloured scarlet. The new scarlet, or Bow dye, is obtained in this manner; and it is said, that our most beautiful and lasting-coloured fine cloths owe their superlative excellence to the retentiveness given by our fine grain-tin; insomuch, that the English superfine broad-cloths, dyed in grain by the help of this ingredient, are become famous in all markets of the known world.

Mr. Pryce apprehends, that the purple dye of the Tyrians owed its reputation wholly, or in part, to the use of our tin in the composition of their dye-stuff, as the tin-trade was solely under their own direction.

This colour, however, succeeds only with wool and other animal matters. Attempts have been made, but without success, to give this colour to thread, to cotton, and even to silk, though this latter substance has many properties of animal matters. The solution of tin made with marine acid alone, or with vitriolic acid, does only give to red tinctures a crimson colour, as alum does. Vegetable acids, as vinegar and cream of tartar, are also capable of dissolving tin.

Tin or its compounds are not used in medicine. They do not appear to be of a poisonous nature; but the muriate of tin, taken into the stomach in considerable quantity, speedily induces death, apparently merely from its corrosive qualities. It was formerly recommended for its anthelmintic virtues; but it is possible, says Dr. Lewis, that these may proceed not so much from the pure metal, as from a certain substance of a different or arsenical nature, of which the purest sorts of tin are found to participate.

The principal preparations of tin are as follow:

TIN, *Butter of*, is a name given by some chemists to a combination of tin with the concentrated marine acid of corrosive sublimate. It is procured by reducing these substances into small parts, and mixing them together: this mixture will, by degrees, be moistened by attracting the humidity of the air. The decomposition of the corrosive sublimate by the tin is more speedily effected by distillation.

TIN, *Calx of*, is the metal reduced into powder, either by means of fire, or by being dissolved in an acid menstruum, and precipitated with an alkali.

TIN, *Ceruss of*. See *Spanish* WHITE.

TIN, *Diaphoretic of*. See ANTIHECTICUM *Poterii*.

TIN, *Flowers of*, are a kind of white cosmetic, or paint for the complexion, drawn from tin with sal ammoniac, by means of sublimation.

TIN, *Gold-coloured preparation of*, is made by adding six ounces of mercury to twelve of melted tin, pulverizing the cold mass, mixing with it seven ounces of flowers of sulphur and six of sal ammoniac, and subliming in a matrass.

This preparation is called *aurum mosaicum*, and as a medicine is little regarded, though formerly much esteemed against hysterical and hypochondriacal complaints, malignant fevers, and venereal disorders. Upon experiment, it appears to be little more than calx of tin.

TIN, *Salt of*, *Sal Jovis*, is prepared from twelve ounces of calx of tin, and four of aqua regia, diluted with twenty-four of water: after digestion for two days, the vessel is to be shaken, the more ponderous part of the calx suffered to settle, the turbid liquor poured off, and evaporated almost to dryness, and the mass farther exsiccated on brown paper: to the remaining calx half the quantity of fresh menstruum is to be added, and the process repeated. Dr. Lewis's experience has not enabled him to pronounce on the virtues of this salt, which is in taste very sharp and corrosive: he thinks it needless to calcine the metal, as tin uncalcined dissolves much more easily and plentifully, and the solution is in both cases the same. According to Hoffmann, the solution of tin is a strong purgative. Lewis's Mat. Med.

TIN is also a word used by some of the chemical writers to express sulphur.

TIN-*Coping*, in *Rural Economy*, a sort of covering of this kind of metallic substance in the sheet form, which is not unfrequently employed on the upper parts of the frames, stands, or staddles of corn-stacks, for the purpose of preventing destructive vermin from entering or getting into them. It is a cheap, ready, convenient, and useful material in this intention, in many cases, which the arable farmer should not be inattentive to in his stack-yard.

TIN-*Floors*, a contrivance used by our husbandmen who propagate hops, to dry them after the gathering. See OOST.

It is thus done: Let a square brick room be built, with a door on one side, and a long fire-place of a foot wide in the middle, reaching almost across it; let holes be made at the sides of this fire-place, to let out the heat into the room; and at the height of five feet above this, let a floor be made of laths of an inch thick, laid lattice-wise. Let this be covered with great plates of double tin, taking care that the joinings of the tin be well soldered, and lie upon the laths, nor over the interstices, which may be about four inches wide. Let a row of boards be fitted round the edge of

this floor, to keep the hops from falling off; then lay on a covering of hops of a foot thick, and make a small fire of charcoal in the mouth of the fire-place, and the hops will dry very quickly and very regularly. They may be continually stirred about while drying, and, when dry, a part of the boarded edge of the kiln may be taken down, and the dried parcel thrust out, and a fresh parcel laid on in their place. A very small quantity of fuel is sufficient in this way, and any fuel will do, for the smoke never comes at the hops. There is a very great improvement still upon this method of drying hops, used by some people: this is the making of a wooden cover, of the size of the tin-floor; this is covered with plates of tin nailed on, and is suspended over the kiln in such a manner, that it may be let down at pleasure, when the lower parts of the hops are dry. This is to be let down within ten inches of their surface, and there it acts as a reverberatory, and drives back the heat on the upper ones, so that they are dried as soon as the lower ones. Thus all the trouble of turning is saved, and the hops are much better dried than in any other way. Mortimer's Husbandry, p. 186. See VENTILATOR.

TIN-*Foil.* See FOIL, FOLIATING, and LOOKING-GLASS.

TIN-*Hatch*, in *Mining*, a term used by the people of Cornwall, to express the opening into a tin-mine. They also call it *tin-shaft*.

They make several openings in the sides of the hills where they expect veins of ore to be. All these, except that which opens on the head of the mine, are called *essay-hatches*; but that which does so, is made their entrance afterwards, and changes its name to that of the tin-hatch. See HATCHES and SHAFT.

TIN-*Hoop for Cheese*, in *Rural Economy*, a light thin hoop constructed of this sort of sheet metallic substance, that is sometimes employed in cheese-making, for holding and keeping the curd together while it is breaking and being crumbled down into the filling-vat, in order to prevent the trouble of raising and holding up the corners of the cloth which is made use of in the business. It is usually about nine inches in breadth, and formed so as exactly to fit the top part of the cheese-vat on which it rests when used. These hoops are sometimes made of other materials, as wood, &c. and are useful in saving time and trouble.

TIN-*Ore*, called *tin-stuff* by the miners in Cornwall. See TIN-*Stone*.

M. Gellert directs, that ores of tin should be assayed in the following manner: Mix a quintal of tin-ore, washed, pulverized, and twice roasted, with half a quintal of calcined borax, and half a quintal of pulverized pitch; these are to be put into a crucible, moistened with charcoal-dust and water, and the crucible placed in an air-furnace: after the pitch is burnt, give a violent fire during a quarter of an hour, and then withdraw the crucible. If the ore be not very well washed from the earthy matter, as it ought to be, a larger quantity of borax is requisite, with some powdered glass, by which the too quick fusion of the borax is retarded, and the precipitation of the earthy matter is prevented. If the ore contains iron, to the above mixture may be added some alkaline salt. See MOOR-*Stone*.

The method of assaying tin-ore, says Mr. Pryce, is very easy; for in its form and size of black tin (which is the ore dressed by stamping, several washings, and calcination, if mineralized with vitriolic, arsenical, or sulphureous pyrites) great part of the work is done, and little more remains than fusion, which is accomplished by a red heat in the following process: Take four or five ounces of black tin as emptied from the sacks, mix it well with about one-fifth part of its weight of powdered culm; put the mixture in a black-lead crucible, on the wind furnace, and, in about twenty minutes, the metal will be found precipitated to the bottom of the crucible, the culm and scoria floating on the tin. On the surface of this matter there will be globules of tin; and therefore the mixture should be stirred with an iron rod, to make them fall into the tin at the bottom. Close the furnace, and let the whole remain in fusion from three to five minutes. Keep in readiness an iron or brass mortar, and an ingot-mould about six inches long; pour the tin into the ingot, and empty the culm and scoria into the mortar, scraping off what remains in and about the crucible with a sharp iron. As soon as cold, put them into another mortar, and pulverize them gently, so as to separate the scoria from the largest of the globules of tin. Select the larger globules, and pulverize the remainder a second time; then put this stuff, twice powdered, on a shovel, and passing it often through water, in the same manner as the lighter parts are washed from ores in vanning, and the smaller globules will remain on the shovel; and these, with the larger (both together being generally called *pillion-tin*), being added to, and weighed with the ingot, shew the produce in metal of the four or five ounces assayed. See Macquer's Chem. Dict.; and Pryce's Min. Corn. p. 269.

TIN-*Plates*, an article of manufacture very common among us, and vulgarly called *tin*. It is iron plated over with tin. The French call it *fer blanc*, white iron, as we sometimes do in England. It was once known under a distinct name, *lattin*, under which article the process of manufacturing it is described.

The process used for this purpose near Caermarthen, in South Wales, which is described by Mr. Donovan, in his "Descriptive Excursions through South Wales in 1805," is as follows:

The iron-ore employed in this manufactory is the common kind of the country, intermixed with a large portion of the fine hæmatite from Ulverstone, in Lancashire, which gives a very fine metal. This too is smelted with charcoal instead of coke, to produce a metal of the greatest purity and extensibility, and closeness of texture, which qualities are particularly required in this manufacture. The reduced ore is smelted in the usual manner, and cast into pigs, which are then wrought by the hammer into long flat bars, that are afterwards cut into pieces of about ten inches in length. These are then wrought into plates by being heated red-hot, and passed through a flatting-mill, which consists of two large cylinders of steel, case-hardened and secured in a frame of iron. These are placed contiguous to each other, but with a certain interval of space, and revolve in a contrary direction, so that when one end of the bar is thrust in the space between the cylinders, the whole is drawn through and proportionably extended and flattened in the passage. The distance between the cylinders, which of course determines the thickness of the plate, is maintained and regulated by screws which can be altered at pleasure. When the bar is thus made into a plate of twice the thickness of the ordinary plates, it is heated red-hot, cut in two by a pair of shears, and one piece folded exactly over the other, and both repassed repeatedly through the cylinders till the folded plate has extended to the same length and breadth as the plate was before cutting. It is then clipped round the edges, and the two plates torn asunder (which requires some little force) after which they are each finished by passing through a finer rolling-press, so as to take away every crease or inequality in the plate, and those that are too rough to pass through this finer press are thrown aside.

The plates are then steeped in a very weak acid liquor, and when taken out are scoured thoroughly with bran, so as

to be quite bright and poliſhed to enable the tin to adhere. The tin is melted in deep rectangular crucibles, and kept fluid by a moderate charcoal fire beneath. To prevent its calcination, a quantity of greaſe prepared from linſeed-oil and ſuet is conſtantly kept floating on the ſurface of the tin, and renewed as it evaporates off, which gives an exceſſively nauſeous ſtench. The plate is then taken up by one corner by a pair of pincers, and dipped vertically into the tin, and when withdrawn is found beautifully white and reſplendent with the coating of this metal that adheres to it. This dipping is repeated three times for what is called *ſingle tin-plate*, and ſix times for the *double plate*. The plates are then only cleanſed and ſorted, and are fit for uſe.

We ſhall here add, with regard to the hiſtory of this manufacture, that in the year 1681, tin-plates were made in England by one Andrew Yarranton, who was ſent to Bohemia to learn the manner of making them. But the manufacture was diſcontinued by his employers, and afterwards ſo much diſregarded, as to be reckoned among the projects called bubbles of the year 1720; however, it was revived, and brought to ſuch perfection about the year 1740, that very little of it was imported from foreign parts; our own plates being of a finer gloſs, or coat, than that made beyond ſea, the latter being hammered, and ours being drawn under a rolling-mill. And. Hiſt. Com. vol. ii. p. 175, 361.

The two principal wholeſale houſes for this manufacture in London, are thoſe of Jones and Taylor in Tottenham-Court Road, and Howard and Co., in Old-ſtreet Road.

Tools

TOOLS, ſimple and popular inſtruments, uſed in the more obvious operations, and particularly in the making of other more complex inſtruments.

The term *tool* is particularly uſed by canal-makers, for a kind of ſtrong curved ſpade or ſhovel employed in canal-works.

Tools are divided into *edge-tools*, *ſpring-tools*, *pointed-tools*, &c.

Mr. Parkes, in the fourth volume of his "Chemical Eſſays," has given a hiſtory of the origin and progreſſive improvement of edge-tools, and an account of the materials of which they were conſtructed. It appears from Goguet's "Origin of Laws," to which he refers, that as many of the ancient nations had no knowledge of iron, they uſed ſtones, flints, the horns and bones of various animals, the bones and ſhells of fiſh, reeds, and thorns for every purpoſe in which the moderns now uſe edge-tools of iron and ſteel. Spears and other inſtruments for exterminating wild beaſts, and even implements of agriculture, were formerly made with gold and ſilver; and inſtead of theſe was afterwards ſubſtituted copper, as a metal more eaſily to be procured than malleable iron. The abundance of celts and other ancient inſtruments, found in various parts of the globe, ſhews that copper and braſs were formerly in very general uſe. From the prodigious number of copper inſtruments of different kinds and ſizes, which have been found in this country, ſuch as axes, ſwords, ſpear-heads, arrow-heads, &c. known among antiquaries by the general name of celts, it is evident that our anceſtors were well acquainted with the art of forming metallic copper in any way which they thought proper; whereas the uſe of metallic iron is comparatively of late introduction. At the time of the firſt Roman invaſion, this metal was ſo rare, that the Britons fabricated their money with it, and even their ornamental trinkets. But the Romans having made themſelves maſters of the country, eſtabliſhed imperial founderies for making iron, and conſtructed forges for manufacturing ſpears, lances, battle-axes, and implements of every kind, in different parts of the kingdom. (See Cæſar, de Bell. Gall. lib. v. c. 12. Henry's Hiſt. of Britain, vol. ii. p. 139, 140.) At the battle of Hamilton, in 1402, the repulſe of the Scots appears to have been entirely owing to the excellent temper of the arrows which were employed by the Engliſh army. Swords alſo were then in uſe, and Sheffield was, even then, famous for its cutlery. Table-knives, it is ſaid, were firſt made in London in 1563, by one Thomas Matthews of Fleet-bridge.

Good edge-tools cannot be made without ſteel; and of this there are various ſorts (ſee STEEL); ſuch as bliſtered, ſhear, ſpur, ſtar, and caſt ſteel; beſides which there is a kind of German ſteel, made immediately from the iron ore, by ſimple fuſions. (See alſo WOOTZ.) The cheapeſt

 edge-

edge-tools, and other lefs important articles, are ufually made with the firft-mentioned kind, united to a large proportion of bar-iron. Clothiers' fhears, firmer chifels, plane-irons, coopers' adzes, fcythes, reaping-hooks, and large knives, are commonly made with fhear-fteel: for the method of manufacturing it, fee STEEL. The fpur and ftar fteel are ufed only for particular purpofes, according to the fancy of the matter cutler. Caft-fteel is ufed for the beft penknives, fciffars, and razors; and fine faws, furgical inftruments, and all edge-tools which require a fine polifh, and various other implements employed in cutting iron, are all made with caft-fteel. The fuperior beauty of inftruments made with caft-fteel would have occafioned a very great confumption of this article, if it had not been for the difficulty of welding, or uniting it properly with iron, and which occafioned its being ufed at firft only for thofe fmaller inftruments, fuch as lancets and penknives, which are generally made entirely of fteel. But fince the difcovery made by fir Thomas Frankland (for which fee WELDING), caft-fteel has been brought into more extenfive ufe, and the inftruments that are thus conftructed, are much better than thofe which are made entirely of caft-fteel. The circumftance of an inftrument having its back made of iron, renders it not fo apt to fly from the work to which the edge or fteel part is applied, and eventually lefs liable to break.

Many artifts, long after the invention of caft-fteel, ufed to unite it to the iron by means of rivets. Hoes are ftill made by riveting or fcrewing the back, together with the eye, upon a blade made with caft-fteel. We cannot minutely recite the various manipulations that are practifed in the manufacture of different edge-tools. The reader will find information of a more ample kind in the work of Mr. Parkes, above cited. (See alfo our article CUTLERY.) We fhall, however, felect the following particulars: the cooper's adze and the carpenter's axe are firft formed by the white-fmith, in iron, together with the eye for the helve. The inftrument is then heated again, and the edge of the cutting part is flit down with a chifel, and this flit is filled with a thin piece of fteel, of a correfponding fize and form. The iron, that has been flit upon, is folded down upon the fteel, and the whole again heated to a welding heat, when the fledge-hammer quickly unites the iron and the fteel into one compact mafs. Scythes and fuch other large inftruments are forged at the mill, by means of a large hammer, moved by water, and the procefs is called "fkelping." Augers, gouges, large chifels, table-knives, razors, and other inftruments of a fimilar bulk, are forged upon a large anvil by the principal workman, aided by an affiftant called the "ftriker," who ftrikes occafionally with a fledge-hammer. Penknives, lancets, gravers, furgical inftruments, and other fmall edge-tools, are generally forged on a fmall anvil firmly fixed within a large one, in order to give greater fteadinefs. Thefe are ufually fafhioned out of fteel only, and forged by one workman fingly and alone. Sciffors are alfo forged by a fingle hand; but the anvil on which they are fafhioned is of a peculiar conftruction, having *boffes* or *dies*, and *beak* irons of various fizes occafionally adapted to it, fo as to fuit the different fhapes and dimenfions of the feparate parts of thefe particular inftruments.

It fhould have been noticed, that many other tools befides the axe and the adze are originally forged out of a piece of iron, with a little fteel welded to it for the cutting part of the inftrument.

The real Damafcus fword-blades are faid to be compofed of flips or thin rods of iron and fteel bound together with iron wire, and then firmly cemented together by welding.

It is well known that it is the circumftance of drawing down the fhear-fteel under the tilt-hammer that gives it the fuperiority over common fteel. (See TILT-*Hammer*, and TILTING *of Steel*.) Mr. Bingley therefore fuggefts in his patent, that, if he could roll out his fteel much thinner than it had ever been done before, he fhould much improve its quality: and accordingly a very thin piece of fteel is let into the face of a plane-iron made of caft-iron; and, as the fteel for this particular purpofe has to go through the rollers feveral times to make it fufficiently thin, it becomes of a peculiar texture, and the tool made with it is found to fuit the joiner much better than the plane-irons heretofore in ufe.

In the manufacture of edge-tools, the procefs which immediately fucceeds the forging is that of *hardening*. All thefe cutting inftruments are therefore fafhioned when the metal is in its original foft ftate; and when they have attained the intended forms, they are heated afrefh to a particular temperature fuitable to the article. When they have acquired that degree of heat, they are inftantly plunged into cold water, which gives them great hardnefs, and renders them capable of cutting foft iron, or even fteel. See TEMPERING.

Turning

TURNING, in the *Mechanical Arts*, is the operation of ſhaping wood, metal, or other hard ſubſtances, into a round or oval figure, by the aid of a machine called a *lathe;* which ſee.

In turning, the work or ſubſtance to be operated upon is placed in the lathe, and made to revolve with a circular motion about a fixed right line as an axis of motion; and the exterior ſurface is worked to its intended figure by means of ſome kind of edged tool, which is preſented to it and held faſt down upon a fixed reſt. The protuberant parts of the work, by its rotatory motion, are carried againſt the cutting edge, and cut off, ſo as to reduce every part of the outſide ſurface, to an equal diſtance from the axis of motion, and of courſe it will be of a circular figure.

The articles which admit of being turned to give them their figure, are all ſuch as combine the three following properties: 1. That they may be ſuppoſed to have an imaginary right line or axis paſſing centrically through the whole length of the piece: 2. That all the ſections which can be made by planes perpendicular to ſuch axis ſhall be circular: and 3. That the centre of all ſuch circles ſhall coincide with the axis or centre line.

It ſhould be obſerved, that a piece of work may have two or more centre lines in different parts or in different directions; but it muſt in that caſe be formed or turned at two or more ſucceſſive operations, becauſe what can be done at once fixing in the lathe, muſt come within the above definition.

The work may be turned hollow, ſo as to make a cavity withinſide; or work may be turned on the outſide, to give form to the external ſurface; and frequently work is turned both without and within; but in either caſe, the above definitions will apply.

Diodorus Siculus ſays, the inventor of the art of turning was a nephew of Dædalus, named Talus; and that the reputation which he acquired by this invention excited the jealouſy of Dædalus, and induced him to put Talus ſecretly to death. Pliny aſcribes it to Theodore of Samos, and mentions one Thericles, who rendered himſelf very famous by his dexterity in managing the lathe. With this inſtrument,

ment, it is said, the ancients turned all sorts and kinds of vases, many of which they enriched with figures and ornaments in basso relievo. Thus Virgil says:

"Lenta quibus torno facili superaddita vitis."

The Greek and Latin authors make frequent mention of the lathe, and Cicero calls the workmen who used it, *vascularii*. It was a proverb among the ancients, to say a thing was formed in the lathe, to express its delicacy and justness.

The art of turning is of considerable importance, as it contributes essentially to the perfection of many other arts. The architect uses it for many ornaments, both within and without highly finished houses. The mathematician, the astronomer, and the natural philosopher, have recourse to it, not only to embellish their instruments, but also to give them the necessary dimensions and precision: in short, it is an art absolutely necessary to the mechanist, the goldsmith, the watchmaker, the joiner, the smith, and others.

As the operation of turning is to be performed by the aid of the lathe, the structure of that machine is the first thing to be considered. In our article LATHE, we have given a description of the most perfect kind of lathe, made in iron, with a triangular bar; and in the article ROSE-*Engine*, we have described a curious lathe for ornamental turning; but it is to be observed, that a much more simple machine will answer all the common purposes of turning.

The essential properties of a lathe for *outside* work are, first, that it shall have two points which will firmly sustain the work at each end, by penetrating into the ends of the work, and, at the same time, allow it to turn freely round upon the points: there must be a rest or support to hold the tool upon, and also some means of turning the work round upon the points. A lathe to turn hollow or *inside* work will not admit of a point of support at each end of the piece, and therefore the work is firmly fixed to the extremity of a spindle, which is called a *mandrel;* when the mandrel is turned round, the work revolves with it, and the tool can be applied at the end of the work, to excavate or turn it hollow withinside, or to turn it on the outside, as required.

Lathes are made in a great variety of forms, and put in motion by different means: they are called *centre lathes*, where the work is supported at both ends; and *mandrel, spindle*, or *chuck lathes*, when the work is fixed at the projecting extremity of a spindle.

From the different methods of putting them in motion, they are called *pole lathes*, and *hand-wheel lathes*, or *foot-wheel lathes*. For very powerful works, lathes are turned by horses, steam-engines, or water-wheels.

The lathes used by wood-turners are generally made of wood, in a simple form, and are called *bed lathes:* the same kind will serve for the common turning of iron or steel, but the best work in metal is always done in iron lathes, which are sometimes made with a triangular bar, and are called *bar lathes*, (such an one is described in the article LATHE); small ones, for the use of watch-makers, are called *turn-benches*, and *turns;* but there is, in fact, no proper distinction between these and the centre lathes, except in regard to size, and that they are made of iron and brass instead of wood.

The *centre lathe* is the most simple of all others. Two beams of wood are fixed horizontally upon legs, like a bench, and form what is called the *bed*. The two beams are fixed together, parallel to each other, and at a small distance asunder, so as to leave a space or narrow groove between them, nearly the whole length of the bed. This groove is to receive the tenons at the lower ends of the *puppets*, which are short posts rising perpendicularly from the bed, and firmly fixed thereto by means of cross wedges, put through the tenons beneath the bed; for the tenons are of sufficient length to descend quite through the groove in the bed, and project beneath sufficiently to receive the cross wedges, which being driven in, draw the bases of the puppets or posts so firmly down upon the surface of the bed, that they will stand firmly erect upon it; or by withdrawing the wedges, the puppets become loose, and can be fixed in another part of the bed, in order that the distance between the two puppets may be made to correspond with the length of the piece of work to be turned. One of the puppets has a pin or *pike* of iron fixed into it, and the other one has at the same level the centre *screw*, working through a nut fastened in the puppet: both the screw and pike have sharp points made of steel, hardened and tempered, that they may not wear away. They must be exactly opposite, and in a line with each other. The piece of work, suppose for instance it is a roller of wood, is supported by its ends between the points of the pike and the screw, that it may turn round freely. The *rest* for the support of the tool is a rail or bar, extending from one puppet to the other; it lies in hooks, projecting from the faces of the puppets.

The work is put in motion by means of the *treadle*, which is worked by the turner's foot; a *string* or catgut is fastened to the treadle, and passing two or three turns round the work, it is fastened to the end of an elastic *pole*, fixed to the ceiling over the turner's head.

The workman stands before his lathe, having one of his feet on the treadle to give it motion; he places a sharp *gouge* or *chissel* on the rest, and approaches the edge of it gently to the piece of work; then pressing the treadle down by his foot, the string turns the work round, and the chissel or gouge being held firm upon the rest, and so as to touch the wood, it will cut it to a circular form. When he has brought the treadle to the ground, he releases the weight of his foot, and the elasticity of the pole draws up the treadle, turning the work back again; during which retrograde motion, he withdraws the chissel from the work, as it would not cut in this direction, though it might impede the motion of the wood, and would injure the edge of the tool. He must perform his work gradually, without leaving ridges; and when he meets with a knot in the wood, he must go on still more gently, otherwise he would be in danger both of splitting his work and breaking the edge of his tool. For turning light work, a bow, such as is used for shooting arrows, is suspended by its middle over the lathe; the string is then tied to the middle of the bow-string, in lieu of the pole, and acts in the same manner.

The common centre lathe is a very imperfect machine, when worked in this manner; yet its simplicity is a great recommendation, especially among country workmen, who use it to make various sorts of common articles of household furniture in soft wood, as stool and table legs, stair-case rails, &c.

In centre lathes, the work is sometimes put in motion by means of a large wheel, turned by one or more labourers; the wheel should be heavy, that its momentum may be sufficient to overcome any moderate obstacle in the work; and the frame in which it is mounted must be of sufficient weight to stand steady, and not be liable to move, by the exertions of the man turning it. An endless line is used, to communicate the motion of the wheel to the work; it passes round a groove in the circumference of the wheel, and after crossing, like a figure of 8, goes round a small pulley, fixed upon the work. By this means, when the great wheel is turned, it gives a rapid rotatory motion to the matter to be turned, and with a much greater power than can be obtained from the treadle, with the additional advantage of the work turning always the

the ſame way round, ſo that the turner has no need to take his tool off the work.

The centre lathe will turn any kind of work which will admit of being ſupported at both ends; and it is uſed by mill-wrights and iron-founders, for turning mill-ſhafts, axles, rollers, and other iron-work. For ſuch purpoſes, the lathe muſt be made exceedingly ſtrong, and with nuts and ſcrews to faſten the puppets down upon the bed, inſtead of wedges; the reſt muſt be made in iron, with the requiſite adjuſtments for placing it cloſe to the work, at that part where it is required to be turned. To put the work in motion, the centre pin or point in one of the puppets is made to project conſiderably, and has a pulley fitted upon it, ſo that it can turn freely round upon the pin by means of an endleſs band or ſtrap, which communicates the motion from a great wheel. In theſe large lathes for iron-work, the wheel is commonly turned by horſes, or by a water-mill or ſteam-engine. From the pulley a pin projects in a direction parallel to the centre pin, and a piece of iron, called a *driver*, is ſcrewed or clamped faſt upon the end of the piece of work, ſo as to project from it ſufficiently to be intercepted by the pin which is faſtened into the pulley: by this means, the motion of the pulley is communicated to the work. The tools employed for turning iron and other metals are different from thoſe uſed for wood, as we ſhall afterwards deſcribe.

The *ſpindle* or *mandrel lathe* will turn hollow or internal work, and is equally well adapted to turn centre work as the centre lathe. In *Plate Turning*, *fig.* 1. we have given a repreſentation of one of theſe, which is on a very good conſtruction, made by Meſſrs. Holtzapfel and Deyerlien: it is put in motion by the foot, ſo that the turner has both his hands at liberty to direct the tools. A A are upright legs, to ſupport the bed B, which conſiſts of two pieces or bars of caſt-iron, put together, and leaving a ſmall crack between them: C D is a caſt-iron frame, which is faſtened down upon the bed B, and ſupports the ſpindle or mandrel *a b*: E is the back puppet, which is uſed to ſupport one end of a piece of work, as is ſhewn in the figure at G, when the other end is fixed to the end of the mandrel, and turned round by it: the back puppet, E, has a cylindrical pin accurately fitted into it at the upper part, and the end of the pin is formed to a ſharp conical point, proper to penetrate and ſupport the end of the work: this point is called the *back centre*. A ſcrew *e* is tapped into the puppet, ſo as to preſs on the oppoſite end of the pin, and force it towards the work; and there is likewiſe a clamp ſcrew, E, at the top, to bind or faſten the pin into its ſocket. The back puppet is faſtened down upon the bed, by means of a tenon entering into the groove, through the bed B, and a ſcrew deſcends from the tenon quite through the bed, and projects beneath it: upon this ſcrew a nut *g* is tapped, and by turning it, the ſhoulder of the puppet E is drawn down firmly upon the bed; but when the nut is looſened, the puppet can be ſlided along the bed to place it at any required diſtance from the end of the ſpindle, according to the length of the piece of work G. It is neceſſary that the point of the back centre ſhould in all caſes be preciſely in the centre line of the axis of motion of the ſpindle *a b*; and for this purpoſe, the bed muſt be made very ſtraight, and flat on the upper ſurface; the groove through it ſhould alſo be perfectly ſtraight and parallel, and the tenon at the lower end of the back puppet muſt be exactly fitted to the groove: the frame of the mandrel muſt be ſo fixed on the bed, that the centre line of the mandrel will be exactly parallel to the bed, and to the groove in the bed.

Mandrels are mounted in different ways, but they are always made of ſteel at the parts where they are ſupported in the collars, which collars ſhould be alſo made of ſteel, and hardened, ſo as to have little friction. The neck of a mandrel muſt be very accurately fitted into the collar, ſo as to have no ſhake or looſeneſs, at the ſame time that it can turn round quite freely.

The neck at one end projects beyond the collar, and the projecting part is formed to a ſcrew, for the purpoſe of fixing the work to it. A variety of pieces, called *chucks*, are fitted upon this ſcrew, and each chuck is adapted to hold a different piece of work: the chucks ſcrew up againſt a ſhoulder on the end of the mandrel, and by the motion of turning round in the direction in which the lathe works, the chuck ſcrews itſelf faſt on againſt the ſhoulder; but if the lathe is ſtopped, and the chuck is turned in the oppoſite direction, it will unſcrew and come off, and a different chuck may be put on. In ſome lathes, the neck of the mandrel is perforated, and cut withinſide, with a female ſcrew adapted to receive a male ſcrew on the chuck: the effect is juſt the ſame as the above deſcribed. The oppoſite end of the mandrel to that on which the chucks are ſcrewed, muſt be ſupported either by a point or in a collar. In general, the mandrel is made with a point at one end; and the other end, which has the ſcrew to fix the work to it, is formed with a neck, proper to run in the collar, and with a ſhoulder on the neck, to ſtop the neck from going through the collar. The mandrel repreſented in the drawing has a neck and collar at each end, for a purpoſe which will be explained. When the mandrel is made with a pointed end, the point muſt be received in the end of a ſcrew tapped through the part D of the frame of the mandrel, juſt in the place of the end *a* of the mandrel. By turning this ſcrew, the mandrel can be adjuſted to run very correctly in length; and to prevent the ſcrew from turning back when the lathe is in motion, a nut is placed on the ſcrew, beyond the part *d*: this cauſes ſuch a preſſure upon the threads of the ſcrew, that it is in no danger of turning back, as it would otherwiſe do with rough work. The mandrel, by this means, runs very ſteadily and accurately in its bearings, and it is plain that any piece of work, which is firmly attached to the end of it by means of the ſcrew before mentioned, may be turned by a tool held over the reſt, in the ſame manner as if it were mounted between centres, but with the advantage that it be turned at the end, to make hollow work when required.

The mandrel is turned round by a band of catgut paſſing round the pulley *h*, and alſo round the large foot-wheel H, which is made of caſt-iron, and fixed on the end of the axis I. This axis is bent in the middle, as in the figure, to form a crank, which crank is united, by an iron link K, to the treadle L, on which the workman preſſes his foot. This treadle is affixed by three rails to an axis M, on which the treadle moves. The wheel H is of conſiderable weight in the rim, and being fixed faſt on the axis I, turns round with it: the momentum acquired by the wheel is the power that continues to turn the work while the crank and treadle are riſing, and conſequently while the workman exerts no power upon them.

When the crank has paſſed the vertical poſition, and begins to deſcend, the workman preſſes his foot upon the treadle, to give the wheel a ſufficient impetus to continue its motion until it arrives at the ſame poſition again. The length of the iron link K, which connects the crank with the treadle, muſt be ſuch, that when the crank is at the loweſt poſition, the board L of the treadle, to which the link is hooked, ſhould hang about two or three inches from the floor. To put the lathe in motion, the turner gives the wheel a ſmall turn with his hands, till the crank riſe to the higheſt, and

 paſſes

paffes a little beyond it; then by a quick tread he brings the crank down again, putting the wheel in motion with a velocity that will carry it feveral revolutions: he muft obferve to begin his next tread juft when the crank paffes the higheft point, and then it will continue running the fame way with a tolerable regular motion, if he is punctual in the periods of his treads. The foot-wheel, by means of the band, caufes the mandrel to revolve very rapidly, fo that it will perform its work very quick, and the workman muft acquire a habit of ftanding fteady before his work, that he may not give his whole body a motion when his foot rifes and falls with the treadle.

The reft N of this lathe is fixed on the bed of the lathe by its foot, which is divided in the manner of a fork, to receive a fcrew-bolt: this bolt paffes down through the lathe-bed, and faftens the reft at any place along the bed, by a nut *k* beneath. The groove in the foot is for the purpofe of allowing the reft to be moved to and from the centre of the work, to adjuft it to the diameter of the work which is turning. The height of the reft is a matter of fome importance in turning, and in fome work it fhould be fixed higher than others; therefore the piece upon which the tool is laid, is made with a fhank of the form of the letter T. This fhank is a round pin, and is received into a focket in the foot of the reft, and can be held at any height by a clamp-fcrew. As the focket and fhank are cylindrical, the edge of the T of the reft can be placed inclined to the axis of the work when turning cones, or other fimilar work, though the fame purpofe may be accomplifhed by the fcrew, which holds the foot of the reft down to the bed of the lathe, admitting the fork to ftand in an oblique direction acrofs the bed.

The wood-turner employs gouges of all fizes, and chiffels of different forms: the gouges are ufed in the firft inftance to rough out and form the wood, as they cut very rapidly, becaufe they can take a very ftrong chip, and the angles will not ftick in, as would be the cafe with the chiffels. The latter are ufed to fmooth the work, and to reduce it exactly to fhape and fize.

The blade of the turning-gouge is formed nearly half round to an edge, and the two extreme ends of this edge are a little floped off, in the manner of an apple-fcoop, that the middle part of the edge may cut away the prominences of the work; and it has no corners, which would catch and get faft in the rough wood. The hollow part is whetted upon a piece of Turkey-ftone, made with a convex edge, for the purpofe; the outfide is whetted upon a common flat Turkey-ftone, taking care to turn the gouge round, that all parts of the convex edge may fucceffively be fharpened. In turning, the blade of the gouge muft be held confiderably inclined, by depreffing the handle (fee *fig.* 42.), fo that the bevil, or outfide of the edge of the gouge, may come very nearly in the tangent to the circumference of the work, and the cutting edge be above the level of the centre. The turner holds the tool down firmly upon the reft, keeping it fteady, by placing the long handle under his arm.

The turner's chiffels are moftly ground with a bevil on both the flat fides, fo that either fide may be indifferently applied to the work: they are ground up and fharpened on the oil-ftone to a keen edge. In fome chiffels, the line of the edge is inclined to the direction of the blade, inftead of being perpendicularly acrofs it, as in the chiffels ufed by carpenters; in others, the edge is rounded to a femicircle, inftead of being a ftraight line; and others are made with angular points, like fpears. It is difficult to defcribe the proper ufe of each particular tool, as the turner muft employ one or other, according to the particular part of the work which is to be executed. In ufing the chiffel, the reft is raifed confiderably above the centre of the work, fo as to be nearly on a level with the top of it (fee *fig.* 41.), and the line of the cutting edge muft ftand oblique to the axis of the cylinder, fo as to prevent either angle of the chiffel from running into the work. It is neceffary to traverfe the chiffel gradually along the work, but not too faft, otherwife it will leave a roughnefs on the furface.

The turning-tools fhould be fixed in long handles, and the turner holds them firmly down upon the reft, fteadying them by placing the end of the handle under his arm.

The turner fhould be provided with a grindftone, and an oil or Turkey-ftone to fharpen his tools; and he muft have callipers and gauges to afcertain the dimenfions of his work. In order to fix the work in the lathe, he muft have a great affortment of chucks. The chucks for wood-turning are blocks of wood, each having a fcrew, by which it can be attached to the mandrel. The end of the chuck being turned true, and the fhoulder of the fcrew upon the mandrel being alfo turned true, the chuck fixes fo tight to the fpindle, that it becomes as it were one piece with it. Moft of the wood chucks are bored out like a box, and the work is jambed into the cavity. There are other chucks, which are only flat round boards, and the work is cemented or fcrewed againft them; but the generality of chucks are cylindrical blocks, with a cylindrical or conical hole turned in the end, like a box, into which the piece of wood to be turned is driven faft, fo as to be turned round with the mandrel. The chucks are generally hooped with iron, to prevent them from fplitting. When centre-work is to be turned in a mandrel lathe, a chuck muft be fcrewed on the end of the mandrel, which terminates in a fharp conical point.

The lathe fhould be fixed in a place very well lighted; it fhould be immoveable, and neither too high nor too low.

The puppets fhould neither be fo low as to oblige the workman to ftoop in order to fee his work properly, nor fo high, that the little chips, which he is continually cutting off, fhould come into his eyes.

The piece of wood to be turned fhould be rounded, before it is put in the lathe, either with a fmall hatchet made for the purpofe, or with a plane or rafp, fixing it in a vice, and fhaving it down till it is every where almoft of an equal thicknefs, leaving it a little bigger than it is intended to be when finifhed off. Before putting it in the lathe, it is alfo neceffary to find the true centres of its two end furfaces, fo that they fhall be exactly oppofite to each other, in order that, when the centre points of the puppets are applied to them, and the piece is put in motion, no one fide may project out more from the centre line than another. To find thefe two centres, lay the piece of wood to be turned upon a plank, open a pair of compaffes to almoft half the thicknefs of the piece, lay one of the legs on the plank, and let the point of the other mark on one of the ends of the piece when laid flat on the plane with the plank, like a roller, from which plank the point of the compaffes ftands up at a given height above the plane on which the piece lies. Defcribe four marks or arcs on that end at equal diftances from each other round the circumference of the end, by laying the piece fucceffively on four different fides, which arcs interfecting one another, the point within the interfections will be the centre of the end. In the fame manner, the centre of the other end muft be found.

After finding the two centres, make a fmall hole at each of them, into which infert the centre points of the back centre and the mandrel, and fcrew up the back centre, to fix the

the piece fo firmly as not to be fhaken out, and yet loofe enough to turn round without difficulty.

This is the manner of fixing the work when it is to be turned between centres; but if it is required to be hollowed out, the back puppet is removed, and the work muft be fixed in a chuck at the extremity of the mandrel. For this purpofe, a chuck is felected which has a hole in it nearly the fize of the piece of wood, the diameter of which being taken in the callipers (*fig.* 35.), the chuck is fcrewed to the mandrel: the reft is fixed in a convenient pofition, and the hole in the chuck turned out by a proper tool to the fize meafured by the callipers: the hole fhould be rather conical, and the wood, being rafped to the fame figure, is driven in faft by a hammer. By turning the mandrel flowly round, it will be feen if the wood is fixed ftraight in a line with the mandrel, and if not, a blow or two of the hammer, properly directed, will rectify it.

If the piece of wood is not very long, the chuck will be fufficient to hold it firm whilft it is turned; but if it is not, then a fmall centre hole muft be made in the extreme end, and into this the point of the back centre fcrew muft be inferted to fteady the work, until the rough part of the turning is done, and then it may be removed; but it is much more convenient to turn without the back centre, and therefore the turner fits the chuck to the wood with care, fo that it will fix faft in the chuck.

The work being thus chucked, or fixed in the lathe, the reft is fet, fo that its edge is clofe to that part of the work which is required to be turned, and the top of the reft being raifed confiderably above the level of the centre of the work, it is there fcrewed faft.

The turner now puts the lathe in motion by treading with his foot, and takes a gouge, of a proper fize, in his right-hand, and holds it by the handle a little inclined, keeping the back of the hand lowermoft: he grafps the blade of the tool with his left-hand, the back of which is to be turned upwards, and he holds it as near the end as poffible on the front fide of the reft; then leaning the gouge on the reft, he is to prefent the edge of it a little higher than the horizontal diameter of the piece, fo as to form a kind of tangent to its circumference: fee *fig.* 42. This is the beft pofition for cutting, and the tool muft be held very firmly, to prevent the edge being depreffed by the motion of the work, for if it does, it will take hold too deep, and tear the work. The gouge is applied firft to one end of the work, and gradually advanced to the other, turning the work true all the way, and reducing it till the callipers (*fig.* 36.) determine it to be near the intended diameter.

The chiffel is next employed to fmooth the cylinder: its handle is held in the right-hand, whilft the left grafps the blade, and keeps it fteady upon the reft, holding the edge a little inclined over the work, as in *fig.* 41; fo that one fide of the flat part of the blade lies on the reft, and the other fide is elevated, that the plane of the blade, and confequently the line of the edge, is not horizontal, but inclined thereto, fo that one corner of the edge of the chiffel is elevated above the work: then the bottom of the edge of the chiffel, or near the bottom, cuts away a fhaving from the work, and this is the only way in which it will cut; for if the edge of the chiffel is held parallel to the axis of the cylinder, it acts parallel to the length of the grain of the wood, fcraping away the fibres, one by one, without cutting, and leaves a very rough furface. In the fame manner, the narrow chiffels, formers, and other inftruments, are to be ufed according to the work which is to be done, taking care that the wood be cut equally, and that the inftrument be not pufhed fuddenly forwards, or fometimes more ftrongly than at others; and taking care alfo that the inftrument does not follow the work, but that it be kept firm on the reft, without yielding. The gouge and chiffel are the inftruments by far the moft frequently ufed, and the moft neceffary in this art. Soft woods are almoft entirely turned by them.

To make the end of the work exactly flat, the thin fide of the chiffel is laid upon the reft, fo that the plane of the edge may ftand exactly upright. The hand is depreffed, that the lower corner of the edge may rife againft the work, and cut a deep circle into it, near the end, and being fteadily advanced, cut to the centre, feparating a thin round chip, and leaving the end quite flat. The cutting corner of the chiffel muft be directed exactly perpendicular to the length of the work, in advancing it, otherwife the end will be either concave or convex, and care muft be taken to keep the plane of the edge truly upright, and hold it very firm, for there is danger of the work drawing the chiffel into the end of it, with a deep fpiral cut, like a fcrew, and tearing the work out of the chuck.

A cylinder of wood being formed by the procefs we have juft defcribed, if it is required to turn it hollow withinfide, the reft is fixed oppofite the end of it, with the edge of the reft perpendicular to the length: then a fharp-pointed tool is ufed, to bore fuch a hollow in the end as will form the required cavity, ufing the infide callipers (*fig.* 35.) to determine the fize of it. The fide-tool, which is made with a cutting edge on the fide, like a knife, may be ufed, if it is required to make the bottom of the cavity fquare; or a hooked tool, with the cutting edge at the end of the hook, may be employed to enlarge the infide to the proper fize: the gauge (*fig.* 34.) is ufed to determine the depth to which it is to be turned.

This is the procefs for turning foft woods, which are generally of a fibrous texture: but hard woods, ivory, and bone, are turned with different tools. The points or cutting edges of fome fuch tools are reprefented in *figs.* 23. and 24; they are bevelled only on one fide, and the angle of the edges is obtufe. The round-pointed tool, and the fharp angular-pointed tool, are thofe employed for firft roughing out the work, and by them a number of contiguous grooves are cut in the wood, until its grain is broken and divided, and the irregularities reduced; then an edged tool can remove the remainder: but as the edged tools will only cut or fcrape off thin fhavings, they are not ufed when the work is to be reduced to fize, but only to finifh it. The manner of applying the tools to the work is fhewn in *fig.* 39. and is nearly the fame as for turning brafs, or other foft metal: the upper furface of the tool is directed to the centre of the work, the intention being to fcrape away fhavings in hard wood, and in foft to cut chips, as at *figs.* 41. and 42. The graver (*fig.* 40.) is a very ufeful tool for hard wood: the manner of ufing it, as well as other tools, will be defcribed when we come to fpeak of turning in metal.

After the work is completely turned, it is next to be polifhed, and this cannot be done with the inftruments hitherto mentioned. Soft woods, as pear-tree, hazel, maple, &c. ought to be polifhed with fhark-fkin, or Dutch rufhes. There are different fpecies of fharks, fome of which have a greyifh, others a reddifh fkin. Shark's fkin is always better when it has been ufed; at firft, it is too rough for fine polifhing.

The Dutch rufh is the equifetum hyemale; it grows in moift places, among mountains, and is a native of Scotland. The oldeft plants are the beft. Before ufing them, they fhould be moiftened a little, otherwife they break in pieces almoft directly, and render it exceedingly difficult to polifh with them: they are particularly proper for fmoothing the

hard woods, as box, lignum vitæ, ebony, &c. After having polifhed the piece well by fuch means, it fhould be rubbed gently either with wax or olive-oil, then wiped clean, and rubbed with its own turnings or fhavings, or with a cloth a little warm. Ivory or horn is polifhed with pumice-ftone or chalk, finely pounded and put upon leather, or a linen cloth a little moiftened with this: the piece is rubbed as it turns round in the lathe; and to prevent any dirt from adhering to any part of it, every now and then it is rubbed gently with a fmall brufh dipt in water. To polifh metals very finely, the workmen make ufe of a particular kind of earth called tripoli, and afterwards of putty, or calx of tin. Iron and fteel are polifhed with very fine powder of emery; this is mixed with oil, and put between two pieces of tin or pewter, and then the iron is rubbed with it. Tin and filver are polifhed with a burnifher, and that kind of red ftone called blood-ftone. Iron and fteel may alfo be polifhed with putty, putting it dry into fhamoy-fkin.

All kinds of articles in wood are turned in the above manner; but many contrivances are neceffary to mount different things in the lathe.

The fmall figures in the plate reprefent various chucks, which are occafionally employed, and which are adapted for turning different kinds of work.

Figs. 2. and 3. exhibit a fmall wood chuck, which is adapted to be fcrewed to the mandrel at *a*, a hole being perforated in the centre of it, at *b*, into which a fmall piece of wood or ivory is to be inferted, in order to turn it. To hold the work faft in this chuck, it is divided at the end *b* by two faw-kerfs, at right angles to each other, as fhewn in *fig*. 3. fo as to feparate the end into four fegments, which admit of expanding or clofing: a hoop or ferril is fitted on the outfide of the chuck, which part is made tapering, fo that forcing the ferril farther on, will clofe the four fegments together, and bind faft upon the work, which is introduced into the cavity *b*. This is a very convenient chuck for holding fmall pieces of ivory, and particularly for the purpofe of polifhing.

Figs. 12. and 13. exhibit a fimilar chuck, made in brafs, for more delicate work; it is only divided into two fegments.

Fig. 4. is a brafs box, to fcrew to the mandrel, and hold a wood chuck, fuch as we have before explained. Wood chucks are ufually made to fcrew on the mandrel by means of a hole in the chuck, which is cut with a female fcrew within. The objection to this mode is, that the threads of the fcrew on the wood wear away by conftant ufe. In *fig*. 4. a brafs female fcrew, *a*, is cut to fit the fcrew of the mandrel, and at the other end, *b*, is a box, alfo cut with a fcrew withinfide, into which the wood block or chuck is fcrewed, as fhewn by the dotted lines, fo as not to come out without great force: by this means, the fitting of the chucks to the mandrel is not with a wooden fcrew, as in general, but with a brafs one, which will not be liable to get out of the truth, but will always fcrew up to the fame fhoulder. The lathe fhould have at leaft two dozen of thefe wood chucks, with cavities of different fizes, and fome of them hooped with iron at the outer end, to prevent them fplitting. The brafs box is a great fecurity againft fplitting.

Fig. 5. is a very ufeful arbor for turning wheels, collets, or any other flat piece of work that will admit of having a fmall hole in the centre of it. A brafs fcrew-chuck, *a*, is fitted to the mandrel, and a fteel pin, *b*, is fixed into it, and projects an inch or more: the pin is turned true, and the work is fitted faft upon it, either by turning the pin to the fize, or by broaching the hole in the work: and to prevent the work from flipping round upon the pin, it is pinched faft up againft the flat furface of the chuck, as fhewn by the dotted lines, by a nut *d*, which is fcrewed on the end of the fteel pin *b*: by this means, the work will be held faft, and will be carried round by the chuck, fo as to be turned by the application of proper tools upon the reft. Thefe kinds of arbors fhould be of all fizes, to fit the holes in different wheels, &c.

Fig. 10. is a brafs chuck, which is very ufeful for holding fmall pieces of brafs work; it fcrews to the mandrel at the end *a*: the hollow part, *b b*, has fix fcrews tapped through it, and pointing to the centre, as fhewn in *fig*. 11. By fcrewing in thefe fcrews, their points will pinch upon any piece of work which is put into the chuck, as fhewn at *d*, and will hold it firm. The fcrews being regulated, admit of adjufting the work *d* to a true centre with the line of the mandrel.

Figs. 16. and 17. are views of chucks having fimilar properties to the preceding: *a* (*fig*. 16.) is the end which is fcrewed to the mandrel; *b b* is a circle of brafs, having a mortife or opening acrofs the centre of it, as in *fig*. 17; into this opening two fteel dies are fitted, and fcrews *d*, *d*, are placed behind them, to approach them together: the fcrews come through the outfide of the chuck, and have fquare heads, which are to be turned by means of a key. The adjacent furfaces of the two dies are hollowed, fo that they will embrace a piece of wire or other fimilar fubftance which is put between them, and the dies may be cut like a file, to hold it faft. By means of the two oppofite fcrews *d*, *d*, the work may be adjufted to the centre line of the mandrel.

Figs. 20. and 21. are a table-chuck, proper for holding wheels or flat plates by the circumference, whilft the centre parts are turned: *a* is the fcrew to fix it to the mandrel: *b b*, a large circular plate, turned perfectly flat on the front furface. In this plate are grooves, pointing from the centre to the circumference, as fhewn in *fig*. 21: the grooves are adapted to receive clamp-pieces, *d*, *d*, *d*, by means of which the wheel or other work is bound faft againft the flat furface of the chuck. The grooves admit the clamps *d*, *d*, *d*, to be placed at any diftance from the centre, according to the fize of the work, and to place them at thofe parts where it will be moft convenient to apply them.

The form of thefe clamps is fhewn more particularly in *fig*. 22: *f* are fliders of metal, which are fitted to the grooves in the chuck; and the grooves are dove-tailed, fo that thefe fliders can be put into the grooves at the back of the chuck, but will not draw through the grooves into the front. Screws are tapped into the fliders, and draw the clamps, *h*, againft the face of the chuck, and hold faft the work, which is placed beneath their claws. The clamps, *h*, have fhanks projecting from them at right angles, which pafs through the grooves, and keep the clamp from turning round to one fide.

Figs. 35. and 36. reprefent the callipers ufed by turners to take the meafure of their work: they are made of two curved pieces of fteel-plate, united together by a joint. When they are opened, as in *fig*. 36, the dimenfions of a round piece of work may be conveniently taken between their points, as fhewn by the dotted circle; but if the points are clofed together, as in *fig*. 35, fo that they pafs each other, then the callipers are adapted for meafuring the diameter of internal cavities, by the diftances of their points from each other.

Several other kinds of callipers are ufed by turners, but thefe are the moft convenient, as they ferve equally well for infide and outfide dimenfions. Some callipers are made double, like a pair of fciffars; and the points at one end are for infide meafures, whilft the others are for outfide meafures; and the diftances of all the points from the joint being exactly the fame, the infide meafure of any hollow being

being taken by one end of the callipers, the oppofite end will be readily opened to the requifite dimenfions for a folid to fill fuch hollow.

Fig. 34. is a gauge for meafuring the depth of hollow work. A is a ruler, through which is a focket to receive another ruler B; and a clamp-fcrew is fitted through the fide of the focket, to hold the ruler, B, faft in the focket. The edge of the ruler, A, is applied to the end of the work, and the other ruler is then flided through its focket, until the end of B touches the bottom of the cavity; and in this ftate, the clamp-fcrew being faftened, the gauge may be applied to the piece of work in the lathe, to afcertain if the cavity is turned out to the required depth.

Fig. 6. is a chuck for turning wood when it is a long piece, which will admit of being fupported at both ends, or between centres, as it is called. The chuck has a fcrew within the part *a*, to fix to the mandrel, and the other end is of fteel, with a pin *b* in the centre; and on each fide of the pin is a fharp edge *c*, like a chiffel, the line of the edge pointing to the centre of the pin. When a piece of wood is mounted between the points of this centre pin and of the back centre, as we have before defcribed, if the back centre fcrew is turned, it will force the piece of work againft the mandrel and the pin *b*, and the edges *c* will penetrate into the oppofite end of the wood; in this cafe, the motion of the mandrel and chuck *a* will be communicated to the wood, to turn it round. The centre pin *b* is made to project beyond the edges *c*, and by this means the work may be removed from the lathe, and put in again if required, becaufe the centre pin will enter again into the fame hole in the end of the work, and reftore the work to its original pofition.

Fig. 7. is a chuck for the fame purpofe, but it is made with a flat circle of brafs, and three pins, *c*, are fixed in it inftead of the edges *c*, *c*. This kind of chuck is fhewn in ufe in *fig.* 1, to turn a pillar for a baluftrade.

When a piece of metal work is to be turned between centres, the edges or points of the laft chucks cannot be made to penetrate the end of the piece, and therefore a fmall chuck, *b*, (*figs.* 14. and 15.) is fcrewed to the mandrel: in the end of this chuck, at *b*, is a hole, which is made fquare withinfide, and the work has a fquare filed at one end to fit the hole. The other end of the work is fupported by the back centre, a fmall hole being made in the end to receive its point; or if the end of the work is fharp-pointed, the back centre pin is drawn out of its focket, and turned end for end: the end of the pin oppofite to the point has a fmall centre hole for the reception of fuch pointed work. Iron and fteel work may be turned very conveniently by means of a fquare, but not very accurately; and after the work has been taken out of the lathe, and the fquare cut off, if it be required to turn the work again in the lathe, it is very difficult to find the true centre.

All works requiring great accuracy, as arbors, fcrews, axles, fpindles, &c. are turned between centre points, thus: a chuck (*fig.* 8.) is fcrewed to the mandrel by the fcrew in the part *a*, a fteel centre point *b* being formed at the end of it. The point is turned very truly, to be exactly in the centre line of the mandrel. The work is mounted between this point and the point of the back centre; and to communicate the motion of the mandrel to the work, a driver (*fig.* 9.) is fcrewed faft on that end of the work neareft the chuck. The driver is an iron ring, with a fcrew *d* tapped through one fide of it, to pinch the work fo faft as to prevent the driver flipping round upon the work; and on the fide oppofite to the ring is a projecting tail *f*.

The chuck (*fig.* 8.) has a fteel claw *k e* fitted through it, and faftened by a fcrew: the end of the claw is bent at *e* parallel to the direction of the mandrel, fo that the end of it will catch the tail *f* of the driver, and turn it round, together with the work on which the driver is fixed.

The ftem *k* of the claw flides in and out of the focket, through the chuck, in order to remove the claw *e* to a greater or lefs diftance from the centre point *b*, and adapt the chuck to operate upon different fized drivers, for delicate or large work. This is the moft accurate method of turning iron work in a mandrel lathe, becaufe the centre points at the ends of the piece are preferved. When one end of the work is finifhed, the driver may be fhifted to the other end. Such work may at any time be mounted again upon its original centre points, in any kind of lathe, to turn wheels, collets, &c. which may be fitted upon it.

The form of the driver is fhewn in *fig.* 30. In order to make it fit different fizes, the fide of the ring oppofite to the fcrew *d* is made angular, and the point of the fcrew forces the work into the angular part.

This driver may be fixed on either end of the work, whilft the other end is turning; but when it is neceffary to fix the driver on that part of the work which is finifhed, the end of the fcrew *d* is apt to pinch and bruife it; it is therefore proper to interpofe a piece of iron between the point of the fcrew and the work. But it is better to ufe the driver fhewn in *fig.* 31: it is compofed of two bars of iron, united by two fcrews paffing through one bar and tapped into the other: both bars are fomewhat hollowed out in the middle, that they may encompafs the work. If this fhould be found to injure the work, a piece of fheet-lead wrapped round it before the driver is put on will prevent it from damaging the work; and if the fcrews of the driver are drawn very tight, it will carry the work about with fufficient force to bear turning.

When a piece of iron or fteel work is to be turned, the centre points at the ends muft be found with great precifion before it is turned, becaufe it is difficult to cut away great protuberances in metal. The centres are firft found by the compaffes, and marks are flightly punched in the ends by a conical-pointed punch. The workman now places the work in the lathe, between the points of the mandrel and that of the back centre, but without fixing any driver on the work; he then fcrews up the centres, fo as to hold the work juft tight enough to prevent its falling down. In this ftate, by turning it round with one hand, while he holds a piece of chalk againft it with the other, he afcertains whether it is pitched nearly concentric on the points; and if it varies much at any one point, he turns back the fcrew to take out the work, and punches new centre points, or alters the old ones, taking care to move them nearer to that fide which appeared to project fartheft in revolving, and was of courfe marked by the chalk.

When he has, by repeated trials, found the true centre, he fcrews up the centre point fo hard, that it may effectually mark the end of the work, by forcing the points to the bottom of the marks punched; then taking the work out of the lathe, he drills holes in the ends, at the places which the centre points have marked, and to fuch a depth, that the points of the lathe will not reach the bottom. When the work is again returned into the lathe, it will run very nearly concentric, and the driver being fcrewed faft on either end of the work, as is moft convenient, the work will be turned round by the clutch projecting from the chuck.

The work is now ready for turning, which is done by different tools, and applied in a very different manner from the chiffels and gouges for turning wood. *Figs.* 37. to 40. are different examples of the manner of turning metals: a tool applied in the manner of *fig.* 39. operates very well upon

upon brafs and bell-metal. The cutting edge fhould be ground nearly to the angle which is there reprefented, and the upper fide fhould be directed nearly to the centre of the piece; the edge will then fcrape away fhavings from the metal. The tool has fome tendency to retreat backwards from the work, and muft be held firmly thereto. The edges of tools, applied as fhewn in *fig.* 39, may be formed to any of the fhapes fhewn in *figs.* 23. and 24. the angle of the cutting edge being in all cafes nearly the fame.

The graver (*fig.* 40.) is an extremely ufeful tool, and fit for turning any metal or hard wood: it is a fquare bar of fteel, cut off obliquely, and the greateft obliquity of the cutting plane is in the direction from one angle of the fquare to the oppofite angle. This produces a prominent point on one of the angles, which point is applied to the work in the manner fhewn in *fig.* 40. and cuts off continuous fhavings inftead of fcrapings: this is owing to the direction of its edge, which is difpofed obliquely to the motion with which the work meets the edge in its rotation. The turner fhould be provided with gravers of all dimenfions.

Fig. 37. is the action of what is called a *heel* tool for turning wrought iron or copper: the edge of this is applied nearly in a tangent to the work, on the fame principle as the chiffel is applied to cut wood. The heel of the tool is placed upon the reft, and being juft oppofite to the edge on which the preffure or drift of the work lies, the tool cannot efcape from its work, although the preffure upon it is very great, fo much fo, that it would be impoffible to keep the tool to its work, if it were held upon the reft, as in the cafe of the wood chiffel, merely by the lateral friction on the reft. The handle of the heel tool is long, and is held inclined upwards, fo that the workman can reft the end of it on his fhoulder, whilft he holds it very firmly down on his fhoulder and on the reft with both hands. This firm pofition is very neceffary, becaufe the heel tool is liable to draw deep into the work, and take away too large a chip. This tool will cut away thicker chips than any other, being what the workmen term a greedy tool. The requifite height of the reft, to make the edge of the tool a tangent to the proper point, is a matter of importance, and requires the attention of the workman, who can only learn the management of this tool by experience. It is not well adapted for finifhing work with accuracy, but is very expeditious in roughing out wrought iron: it generates fo much heat in working, that it is neceffary to keep it conftantly wet; and in large lathes, a conftant ftream of water is made to fall on the edge at the place where it is cutting. The graver and all other tools work wrought iron and fteel to the greateft advantage when wetted.

Fig. 39. is the tool ufed for turning caft-iron; this fubftance muft be fcraped away, and it is plain from the figure, that the cutting edge is prefented very nearly in the fame manner, with refpect to the work, as in *fig.* 39; but from the hardnefs of caft-iron, it requires a very confiderable force to prefs the edge againft the work, and it would be impracticable to hold it up effectually on the plan of *fig.* 39; hence the tool in *fig.* 38. is bent at the end, and is lodged over the edge of the reft, in the manner of a lever; the handle is preffed down at the extremity, and lifts up the edge againft the work with very great force. The workman muft bear on the handle of this tool with the requifite preffure; and in large work, fuch as cannon and mill-fhafts, he ufually feats himfelf upon the end of the tool, which is made very long in the handle.

Different fubftances require different velocities of motion to cut with the greateft advantage. Wood can fcarcely be made to move too quick; and it is always preferable to take a very thin chip, and move as quick as poffible, than to move flowly, and compenfate for the lofs of time by cutting deep. Brafs and bell-metal may be moved very quick, but not with half the velocity of wood. Wrought iron and copper muft be turned more flowly, and the tool muft be kept wet. Steel fhould go rather flower than wrought iron, for it is liable to have hard veins in it, which the workmen call pins: thefe will be cut through if the work moves flowly, but with a quick motion they will deftroy the edge of the tool: this makes fome workmen think that the pins are actually formed, or that they become hard during the operation of turning, if too great a velocity is ufed. Caft-iron muft move very flowly, indeed it can fcarcely turn too flowly, and the tool applied as at *fig.* 38. will cut a thick chip.

To obtain thefe different degrees of velocity, the foot-wheel of the lathe *fig.* 1. is made with feveral grooves of different diameters, and the mandrel pulley *h* has alfo different fizes. A band can be applied upon any of thefe grooves at pleafure, and the workman finds by experience what velocity is beft for different kinds of work.

The moft experienced workmen prefer a centre lathe to a mandrel lathe, when they have to turn accurate iron-work, which will admit of being poifed between centres; and it is obvious, that the revolving motion of the centre point at the end of the mandrel is of no ufe; and if the point fhould be the leaft out of the centre line, or if the mandrel has any fhake in its collar, the work would not be turned truly. But in a centre lathe, where both points are fixed immoveably, or, as the workmen fay, with dead centres, this cannot happen; and if the work is fcrewed up tight between the centres, fo that there is no fhake, the centre points at the ends of the work muft be precifely in the centre line of the work.

The manner of giving motion to a piece of work in the centre lathe is, as we have before defcribed, by a loofe pulley fitted on the centre pin, and from this pulley a pin projects in a direction parallel to the centre line, fo that it comes exactly in the place of the claw *e* (*fig.* 8.), and turns the driver round when the pulley is put in motion by the band, either from a foot-wheel or hand-wheel.

When the mandrel lathe is ufed for centre work, the centre of the chuck muft be turned very exactly, fo that it does not vary in the leaft from the fame pofition when it turns round; and in all cafes, the mandrel muft be fitted with the moft fcrupulous accuracy into its collar, fo that there will be no fhake; for unlefs this is the cafe, the lathe will not turn chuck-work with any accuracy.

Meffrs. Holtzapfel and Deyerlien make very excellent lathes on the plan reprefented in *fig.* 1. The bed and the puppets are made of caft-iron, and very correctly fitted, fuch lathes poffefs great ftrength: fome of them are fitted up, as in the figure, with a pattern fcrew at the end *a* of the mandrel, for the convenience of cutting fcrews on work. For this purpofe, the mandrel is fitted in a collar at each end, and the necks are cylindrical, fo as to admit of the mandrel moving endways at the fame time that it turns round. On the extreme end of the mandrel, beyond the collar D, a pattern fcrew is fixed, which has the diftance of its threads correfponding with the fcrew that is defired to be cut upon the work, which is fixed in the lathe by a chuck: a piece of brafs, *n*, is provided, which is cut with threads adapted to the pattern fcrew, and which can, by turning a fcrew, be drawn up againft the pattern fcrew, fo as to work in its threads; and in this ftate the mandrel, at the fame time that it turns round, will move endways in its collars with a fcrewing motion; and in confequence, a pointed tool being prefented to the work, and held faft on the reft, will cut a fpiral groove or fcrew upon its circumference. This contrivance is more fully

fully explained in the article Rose-*Engine*. It is the most convenient method of all others for cutting screws, and very accurate, if the pattern screws which are fixed on the mandrel are correctly cut. For all purposes of wood turning, it is undoubtedly the best method, and far preferable to the common one of cutting screws flying, as it is called, that is, by means of the tools 32 and 33, which are applied to the work, and moved along endways at the same time that the work turns round, so that they cut a spiral. (See Rose-*Engine*.) The rapidity and accuracy with which some workmen cut screws in this way exceed belief; but it is only by long experience that this habit can be acquired, and for those who have not had such experience, some mechanical help is necessary. The objections made by accurate workmen to the flying or screw mandrel are, that as the necks must be cylindrical, it cannot be kept so perfectly fitted in its collars as the common mandrels, which have a point at the extremity, and the neck at the other end is made slightly conical, so that it can always be screwed up to fit in the collar. Messrs. Holtzapfels mandrels are made of hardened steel at the necks, and the collars are also hard; they are accurately fitted, and have no shake when new. From the hardness of the materials, they will wear a long time before they get any looseness.

Mr. Maudslay has the most complete set of tools for all kinds of mechanical works at his manufactory, and is particularly well provided with turning apparatus. All his lathes are made with triangular bars, such as is described in our article Lathe, and the mandrels are all formed with conical necks and collars. The bar lathes are very accurate, particularly when the slide-rest is applied to them, as there described. The bed lathe may also have a slide-rest applied, as is shewn under Rose-*Engine*.

If a piece of metal, after being properly turned, is to be bored hollow within, like a gun-barrel, the back puppet is to be removed from the bed of the lathe, and another substituted in its place, having a hole or collar through it, into which the neck or end of the iron is to be correctly fitted, the other end of the iron being supported and turned round by being fitted into a chuck at the end of the mandrel, or else by means of the centre point at the end of the mandrel, and with a driver, as in *figs*. 8. and 9. The rest is to be set opposite the end of the piece where it comes through the collar, and drills or borers are to be applied, similar to those used by locksmiths in boring keys, beginning with a small one and afterwards using larger ones, until the hole is made as wide and deep as necessary. The borers must be held very firm on the rest, otherwise there is danger of not boring the hole straight. The borer should be withdrawn from time to time, to oil it and clean the hole. As it is difficult to make a hole quite round or concentric with the outside by means of borers alone, it is necessary to have also a turning tool considerably smaller than the hole, one of the sides of which is sharp, very well tempered, and a little hollow in the middle. This instrument being fixed in a long handle, is to be introduced into the hollow, and applied with steadiness to the inner surface of the hole, and it will entirely remove every inequality that may have been there before its application.

The collar puppet is only resorted to, when the piece which is to be bored is of considerable length; for if it is short, it will be held sufficiently fast in the chuck, without the necessity of supporting the extreme end.

A collar puppet is sometimes necessary in turning centre work when the work is long, and so slender, that it bends or springs by the stress of the tools: the collar is then applied to support the work at the part where it is weakest and bends most.

Turning of elliptical or oval Work, such as Picture-frames, Snuff-boxes, &c.—This is performed in the same lathe, and with the same tools, as the circular work; but the lathe is provided with a chuck, which causes the work to traverse in a very curious manner, by a motion given to it in a direction to and from the centre of the mandrel as it revolves; so that a tool held up against the work will cut an elliptical figure instead of a circle. Elliptical work has a very singular appearance when in motion; for after the work has been turned truly elliptical, every part of the circumference, except the exact point where the tool was applied, appears to vibrate, or be excentric in a great degree, but that one point of the circumference runs perfectly true and regular, the same as the whole circumference of a piece of circular work does. The mode of action of this ingenious apparatus is rather difficult to describe, and it is first necessary to understand the principle of its action. This is the same as the trammel or elliptic compasses; see *fig*. 29. An octagonal or square board A A, B B, has two grooves cut in its surface, which intersect each other at right angles; this board is held down upon the surface where the ellipse is to be described, with the centre lines of the cross grooves coincident with the two diameters of the intended ellipsis, and of course their intersection will be its centre. The curve D D is traced beyond the circumference of the board, by means of a pen or pencil, which is fixed at F, to a radical bar or beam F G H; this bar carries two other points or pins, G and H, which are attached to sliders, inserted into the cross grooves of the board, as shewn in the figure: the sliders are fitted in truly, so that each of them will have a motion in its respective grooves: thus the slider of the pin H will move along A A; and the slider of G, along the groove B B. By turning about the beam F G H, the sliders go backwards and forwards in their cross grooves with a simultaneous motion; so that when the beam has gone one-fourth way about, one of the sliders will have moved from the circumference of the board A B, to the common centre of the cross grooves; and when the beam has gone half round, the same slider will have proceeded the whole length of the cross, and arrived at the opposite side of the circumference. The same applies to the other slider, and when one slider is at the centre, the other will always be at the circumference.

The pins F and G H can be fixed at any part of the beam at pleasure, (though this is not so represented in the drawing,) for the purpose of setting the trammel to draw any particular ellipsis: thus, place the beam in the direction of the line A A, then the pin G will be in the centre of the cross grooves; now fix F at such a distance from the centre, as is equal to half the small diameter of the ellipse, and set H so far distant from G, as the difference of the two diameters; consequently, from F to H will be equal to half the longest diameter. Now, in turning the beam round from the direction A A, till it comes to the direction B B, the point G will depart from the centre along B B, and H will approach it along A A, till it gets to the centre. Then will the pencil F be so much farther from the centre, as G is distant from H, and the pin has in its circuit traced one-fourth of an ellipse. The beam being turned quite round, will complete the whole curve.

This apparatus may be applied to turning by some modification. Suppose the two cross grooves made in a round board, as large again as that represented in the figure; then, if the whole apparatus be inverted, and the beam F G held fast in a vice, or otherwise, the board with the cross may be traversed round upon the fixed sliders, in the same manner as the beam could be traversed round upon the fixed board. Suppose a tracing point is held to the back of the board, exactly

exactly opposite to the place where the tracing point F is fixed to the beam, and held fast; it is evident that its point will trace the same ellipse on the back of the board, that was described on the surface which the board lay upon in the former instance: or a chissel being held fast in the same spot, will cut the board elliptical when it is turned round; and the chissel being successively applied at different points along the line of the beam, a series of concentric ellipses may be turned in the board, to make mouldings for picture-frames or other ornaments. If the distance of the two fixed pins G and H, and the chissel F, is altered, it will vary the proportion between the two diameters of the ellipsis, in the same manner as before described of the trammel.

The oval chuck is constructed in a different manner from this, though it preserves the same movements. It consists of three parts, the chuck, the slider, and the excentric circle. The chuck *e e f* (*fig.* 27.) is attached to the mandrel by a screw-socket, cut in a piece *f*, which projects from the centre of it behind; and hence the chuck turns round with the mandrel with a circular motion.

The chuck has a dove-tailed groove, formed in it at the front side, for the reception of a slider *g h*, (*fig.* 26.) which traverses freely in the groove: the groove is formed, as the figure shews, by pieces *i*, *i*, screwed to the chuck on each side. In the centre of the slider, in front, is a screw *h*; see also the plan, *fig.* 25. The screw *h* projects from the slider, and by means of it, a wooden chuck may be screwed against the slider, and any work can be fixed in the chuck in the usual manner. The work so fixed, at the same time that it turns round by the motion of the chuck, has a sliding motion across the centre, which motion being given according to a certain law, produces an elliptic motion. The sliding motion is given by the excentric circle (*fig.* 28.); this is a ring of brass, attached fast to the puppet of the lathe, close to the collar, in which the neck of the mandrel runs. The mandrel passes through the aperture *l*; the ring has a flat plate, *m*, to strengthen it, and forming two bends at the ends *m*, *m*, which bends have screws tapped through them, and pointing exactly to each other: these screws are sharp at the points, and are inserted into small holes in each side of the puppet, as is shewn in the plan *fig.* 25. at C, the back of the plate *m* of the circle lying flat against the front of the puppet C; by this means the circle is fixed fast; the two screws are horizontal, and both point to the centre of the mandrel *b*; therefore, by screwing one screw in, and the other out, the whole circle may be moved sideways horizontally, so as to give it any required degree of excentricity from the centre line of the mandrel, and it will be held stationary wherever it is placed.

Fig. 27. is a back view of the chuck, and shews two grooves made through it in the direction of the length of the slider; these admit the shanks of two pieces of steel *n*, *n*, to pass through the chuck, and they are firmly attached to the slider *g*, by a screw for each in front of the slider, as shewn in *fig.* 26. The two inside edges of the pieces *n*, *n*, are exactly parallel to each other, and the distance between them is exactly equal to the diameter of the outside of the ring 28, which ring is included between them, when the chuck is screwed to the mandrel *b*, and the circle fixed to the puppet C, as shewn in *fig.* 25.

Suppose then the circle is set concentric with the mandrel; if the mandrel is turned round, it will cause the chuck *e*, and slider *g*, together with the work attached to the slider by the screw *h*, to revolve. The work will now run in a circle, and turn circular work as usual, because the slider is guided by means of its claws *n*, *n*, which embrace the circle; and will keep the same position in its groove in the chuck during all the parts of a revolution, because the circle is concentric with the mandrel.

To set the chuck for an ellipsis, place the point of a tool opposite the work, at such a distance from the centre of the work, that it will describe a circle of a diameter equal to the breadth or smallest diameter of the ellipsis intended to be turned. This is best done by fixing the tool in the slide-rest. Now turn about the mandrel, till the slider *g* comes horizontal, and set the circle 28 excentric from the mandrel by its screws *m*, *m*; it will of course move the slider *g* in the groove of the chuck, and also the work will move with it to a greater distance from the centre, because the two steel pieces *n*, *n*, at the back of the slider include the circle between them. The quantity of excentricity given to the ring, must be equal to the difference between the two diameters of the required ellipsis, so that the work shall move, or throw out a sufficient distance, to bring the point of the tool as much beyond the circle first described, as the length of the ellipse exceeds the breadth. The point of the tool will now be at one end of the longest diameter, and here we will commence to trace the curve all round. In turning the mandrel round till the slider comes vertical, it must return in its groove to the place it first occupied, *viz.* the centre; because the excentric circle which guides the slider is not excentric in a vertical direction, though it is in the horizontal. In this motion, the point of the tool has cut or described one quadrant of an ellipse, because it gradually approached the centre a quantity equal to the excentricity of the circle. By continuing to turn the mandrel round farther, the circle will cause the slider to move out the other way from the centre in its groove until it comes again horizontal, when it will be at the greatest *throw out*, as the turners term excentricity, and the point of the tool will be at the other end of the longest diameter, having described one half the curve: continuing to move forwards till the slider becomes vertical, it will become concentric again, and the tool will be at the breadth of the ellipse, having finished three quarters of the ellipse; and in turning the next or fourth quarter, the slider throws out till it comes horizontal, and brings the work to the position where we first set out, *viz.* at its greatest excentricity; and with the tool at the end of the longest diameter of the ellipse.

The simple trammel (*fig.* 29.) is not easily recognized in this complicated chuck, although it has all the same movements. Thus, let us return to our first idea of a board with two cross grooves in the back of it, turning round on two fixed pins, which enter the sliders in those grooves. Suppose that one of the pins is extended to a large ring, and the groove proportionably widened to receive it, this will have the same effect. Such a groove is formed by the two pieces of steel *n*, *n*, which have straight edges made truly parallel to each other, and perpendicular to the length of the slider which carries them. The other fixed pin is represented by the mandrel; and the slider being always confined in a right line across it, has the same effect as a pin entering a straight groove.

This ingenious apparatus was invented early in the last century by the celebrated mathematician Abraham Sharp. Before his time, oval-work was always turned in a rose-engine, which had an elliptical pattern.

In turning oval work, the tools must be delicately used, because the circumference moves with an unequal velocity at different parts of its revolution.

Method of ornamenting turned Articles by an Excentric Chuck.—This produces a similar effect to the rose-engine; but as a chuck of this description can be applied to any lathe which has a mandrel and slide-rest, it has been reserved for the present article.

Figs. 18. and 19. are two views of an excentric chuck; a

is a ſocket, which is ſcrewed to the mandrel; and *b b* the chuck, which is formed in the ſame piece with the ſocket *a*; a dove-tailed groove is formed in the front of the chuck, by means of two pieces *d*, *d*, which are ſcrewed to the chuck, and into this groove a ſlider, *e e*, is fitted: to this ſlider a centre pin is fixed very firmly, and upon the centre pin a circle, *f*, is fitted, ſo as to turn round freely; in the front of the circle a ſcrew, *g*, projects, for the purpoſe of fixing chucks to the circle. The ſlider is applied to the chuck, juſt the ſame as in the oval chuck, but is not left at liberty to ſlide in the groove, for a ſcrew, *k*, is applied, which will move the ſlider gradually in the groove, but always holds it faſt where it is placed. By means of this ſcrew, the centre pin of the circle, *f*, can be made either to coincide with the line of the mandrel, or it can be ſet with any required degree of excentricity from the mandrel, as is ſhewn in *fig.* 19, by the difference between the line of the ſcrew *g*, and that of the ſocket *a*.

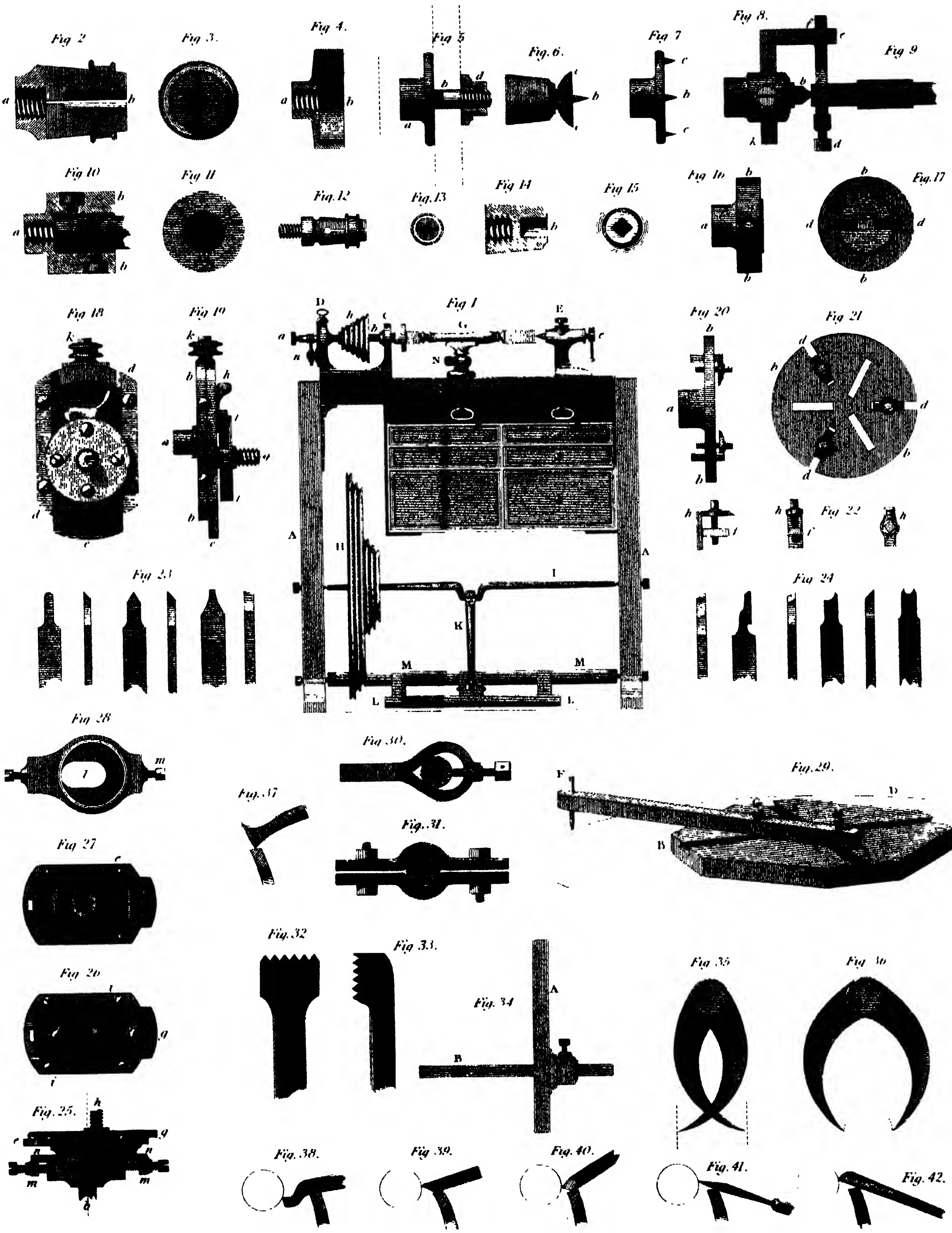
The circle is divided round the edge with notches or teeth, cut at equal diſtances; and a tooth or catch, *h*, is fitted on the ſlider by a centre ſcrew, and has a tooth which can be inſerted into any of the teeth at pleaſure, and will hold the circle faſt from turning round upon its own centre pin. In this caſe, any piece of work, which is fixed to the ſcrew *g*, will turn round with the mandrel, juſt as though it was fixed immediately thereto. The manner of uſing this tool is as follows: when the excentric chuck is ſcrewed to the mandrel at *a*, the ſcrew, *k*, is turned, until the ſcrew, *g*, is brought exactly into the line of the mandrel. A wood chuck is now ſcrewed on at *g*, and a piece of work fitted into it; which work is turned to its required figure, juſt as though the wood chuck was ſcrewed to the mandrel itſelf, without the interpoſition of the excentric chuck, which hitherto has been paſſive. The work being turned, it can be beautifully ornamented on the flat ſurface, by tracing a number of circles upon it. To do this, turn the ſcrew *k*, until the centre of the circle, *f*, is removed to a given diſtance from the line of the mandrel; now apply a tool to the end or flat ſurface of the work, by means of the ſlide-reſt, and turn the mandrel round, until the tool has cut a fine circular line in the ſurface of the work. Now it is evident that this circle will not be in the centre of the work, but removed from the centre thereof a diſtance equal to the degree of excentricity given to the ſlider. Having thus deſcribed one circle, ſtop the lathe, and releaſe the catch *h*; then turn the circle, *f*, round one tooth or notch.

Put the lathe again in motion, and deſcribe another circle by the point of the tool, held exactly in the ſame ſpot as before; but the circle ſo deſcribed will fall on a different part of the work to that circle which was before made, although its centre will be at the ſame diſtance from the centre of the piece of work. The lathe is ſtopped, and the circle, *f*, turned round another tooth: a third circle is then deſcribed; and when as many circles are deſcribed as the whole number of teeth in the circle *f*, the ornamenting is finiſhed. It will conſiſt of as many circles as there are diviſions in the circle *f*, all of an equal ſize, and their centres arranged at equal diſtances, around the circumference of a ſmall circle, which is concentric with the work. The whole produces a roſette or engraved figure upon the ſurface of the work, and the numerous interſections of the excentric circles have a very pleaſing effect to the eye. This kind of work is ſeen on the caſes of many watches; and when well executed, is much eſteemed.

TURNING *Horizontal Hand-Mill*, in *Rural Economy*, an uſeful contrivance of the hand corn-mill kind. It was invented by Mr. Wright, and conſiſts of a ſort of tub or box; the frame of the mill-part of which is three feet ſquare, and three and a half in height. The mill-ſtones are eighteen inches in diameter, and incloſed in the tub or box, ſupported by two croſs-bearers, under which is a lever, having an iron pin or pivot, which runs through the centre of the bed ſtone into a ſocket in the bridge of the upper ſtone or runner, to which is attached the ſhaft and ſpindle, running through the eye of the runner and hopper, and ſupporting the fly-wheel and crank. A piece of wood of a round form, faſtened on the ſhaft, ſerves as a feeder; and above is a ſcrew to regulate the feed according as the mill is turned. On the ſide of the tub or box is a thumb-ſcrew, fixed to the lever underneath, which regulates the ſtones, according as they are turned. The ſhaft runs through the crown-tree or croſs-bar at the top of the frame, on which is the horizontal fly-wheel and crank; to which are attached one or two handles, by means of which the mill is put in motion. Under the ſtones is a drawer; in which are placed three ſieves of different fineſſes; one for taking away the broad bran, another for the coarſe pollard, and the third for ſtopping the fine pollard, and letting the flour paſs into the drawer, which is effected by a ſort of iron fork running through a hole in front of the drawer, and fixing on one of the ſieves.

Small hand-mills of this nature are extremely convenient and uſeful in many caſes.

TURNING.



Published as the Act directs, 1818, by Longman, Hurst, Rees, Orme, & Brown, Paternoster Row, London.

Varnish

VARNISH, or VERNISH, *Vernix*, a thick, viſcid, gloſſy liquor, uſed by painters, gilders, and various other artificers, to give a gloſs and luſtre to their works, as alſo to defend them from the weather, duſt, &c.

There are divers kinds of varniſhes; ſome of the principal of which are as follow:

VARNISH, *Amber*, is prepared in the following manner: Put four ounces of amber into a crucible, and melt it with a ſmall degree of heat, and pour it out upon an iron plate; when cold, reduce it to powder, and add to it two ounces of drying oil, that is, linſeed oil thickened by boiling it up with litharge, and one pint of oil of turpentine, and diſſolve the whole together into a liquid varniſh.

This ſimple amber varniſh is of great uſe for many purpoſes, and is ſaid to be the baſis of the fine varniſhes which we ſee on coaches, and may be prepared without drying oil, by boiling the powder of amber in linſeed oil, or in a mixture of linſeed oil and oil of turpentine. Drying oil is commonly uſed by the workmen; but Dr. Lewis thinks it more eligible to take the oil unprepared, that the boiling requiſite for giving it the drying quality may be employed at the ſame time in making it act upon the amber. It has generally been thought, that amber will not at all diſſolve in oils, till it has ſuffered a degree of decompoſition by fire. But Hoffman relates an experiment, in his Obſervationes Phyſico-Chemicæ, which diſcovers the ſolubility of this concrete in its natural ſtate. Powdered amber, with twice its quantity of oil olive, was put into a wide-mouthed glaſs; and a digeſtor, or ſtrong copper veſſel, being filled about one-third with water, the glaſs was placed in it, the cover of the digeſtor ſcrewed down tight, and a moderate fire continued an hour or more: when cold, the amber was found diſſolved into a gelatinous, tranſparent maſs. In Dr. Stockar's Specimen Inaugurale de Succino, printed at Leyden in 1760, we have an account of other experiments made by himſelf, in conjunction with M. Ziegler of Winterthur; from which we learn, that by continuing a ſimmering heat twelve hours, and confining the vapour as much as ſtone-ware veſſels would bear without burſting, (the danger of which was avoided by making a ſmall notch in the cork-ſtoppers,) powdered amber diſſolved perfectly in expreſſed oils, in turpentine, and in balſam of copaiba: a ſtrong copper veſſel, with a cover ſcrewed on it, ſeems moſt eligible; and for the greater ſecurity, a valve may be made in the cover, kept down by a ſpring, that ſhall give way before the confined vapour is of ſufficient force to endanger burſting the veſſel. Moreover, by digeſtion for a week in cloſe-ſtopped glaſs veſſels, in which the compreſſure could not be very great, ſolutions equally perfect were obtained. The ſolution in rape-ſeed oil, and in oil of almonds, was of a fine yellowiſh colour; in linſeed oil, gold-coloured; in oil of poppy-ſeeds, yellowiſh-red; in oil olive, of a beautiful red; in oil of nuts, deeper coloured; and in oil of bays, of a purple-red. The ſolutions made with turpentine and with balſam of copaiba, were of a deep red colour, and on cooling, hardened into a brittle maſs of the ſame colour. All the ſolutions mingled perfectly well with ſpirit of turpentine. Thoſe made with the oils of linſeed, bays, poppy-ſeeds, and nuts, and with balſam of copaiba and turpentine, being diluted with four times their quantity of ſpirit of turpentine, formed hard, tenacious, gloſſy varniſhes, which dried ſufficiently quick, and appeared greatly preferable to thoſe made in the common manner from melted amber.

An amber varniſh may alſo be made by boiling down ſome colophony, or turpentine, till it becomes black and friable, and melting this in a glazed earthen veſſel, ſprinkling in, by degrees, thrice as much amber in fine powder, with the addition of a little ſpirit or oil of turpentine now and then. When the amber is melted, ſprinkle in the ſame quantity of ſarcocolla, continuing to mix them, and to add more ſpirit of turpentine, till the whole becomes fluid; then ſtrain out the clear

clear through a coarſe hair bag, preſſing it gently between hot boards. This varniſh, mixed with ivory-black in fine powder, is applied, in a hot room, on the dried paper paſte of which the *papier mâché* is made; which is then ſet in a gently heated oven, next day in a hotter oven, and the third day in a very hot one, and let ſtand each time till the oven is grown cold. The paſte thus varniſhed is hard, durable, gloſſy, and bears liquors hot or cold. Lewis's Com. Phil. Techn. p. 367.

An amber varniſh may be otherwiſe made by melting eight ounces of Chio turpentine, and when fluid, pouring into it, by degrees, a pound of fine powdered amber, and ſtirring it; and when it is properly mixed, ſetting it on a fire for half an hour, taking it off, and ſtirring it well, and adding to it two ounces of the white colophony. It is again to be put on a briſk fire, and covered cloſe; when the maſs is perfectly fluid, and taken off to cool, a pound of linſeed or poppy oil, made drying, is to be poured in boiling hot, and ſtirred till it be incorporated with the maſs; and then a quart of hot turpentine is to be added, and the whole well ſtirred. Let it then cool, and ſtrain it off for uſe; when, if it has been properly made, it will be quite clear. See GILDING *on Enamel and Glaſs*.

VARNISH, *Black*, for japanning on wood or leather, is prepared by mixing lamp-black or ivory-black with a proper quantity of a ſtrong ſolution of gum lac in ſpirit of wine. (See JAPANNING.) The lamp-black is commonly preferred to the ivory-black, on account of its uniting better with the fluid, and working ſmoother. The thicker part of the varniſh, which ſettles at the bottom, is uſed with the lamp-black for the firſt coatings, and the mixture applied at different times, in a hot room, one layer after another, is dry, till a full body of colour is obtained; after which, the piece is waſhed over in the ſame manner ſeveral times, with the finer part of the varniſh, juſt tinged with the black, ſo as to make a coating of ſufficient thickneſs to bear poliſhing with tripoli. Iron ſnuff-boxes, mourning buckles, &c. are coloured black, by making them conſiderably hot, and applying on them in this ſtate a thick mixture of lamp-black, with a certain varniſh called gold-ſize, conſiſting of drying oil, turpentine, and the pigment called Naples yellow; but the yellow might be omitted, and the varniſh formed at once by mixing lamp-black with a proper quantity of turpentine and drying oil. The workmen, as Dr. Lewis ſays, frequently employ, as varniſh for metals, a mixture of lamp-black, with the ſcummings, &c. of different oil paints; the mixture is applied with a pencil, and the piece afterwards baked in an oven with a heat ſomewhat greater than is uſed for the *papier mâché*. Naples yellow, a ſuperfluous ingredient in the black varniſh, is the baſis of the dark-brown which we ſee on ſome iron ſnuff-boxes; this pigment changing to a brown in baking with the varniſh. Lewis. See LACQUER.

The excellent black varniſh of China and Japan, which has been hitherto but imperfectly imitated in Europe, and which was formerly thought to be an artificial compoſition of reſinous bodies coloured with black pigments, has been diſcovered by the later travellers into thoſe countries, to be a native juice, exuding from inciſions made in the trunks of certain trees. Mr. Miller, in conſequence of a letter from the abbé Mazeas to Dr. Hales, containing a communication of the diſcovery of a plant by the abbé de Sauvages, which he calls *toxicodendron Carolinianum foliis pinnatis, floribus mininis herbaceis*, and the black juice of which adheres, without the leaſt acrimony, to cloth with more force than any other known preparation, takes occaſion to ſhew, that this American toxicodendron is the ſame ſpecies of plant from which the inhabitants of Japan procure the varniſh with which they ſtain all their utenſils; adding, that the Calicuts are alſo painted with the juice of this ſhrub. This American toxicodendron (ſee POISON-*Tree*) is the ſame plant, as he affirms, which is mentioned by Kæmpfer, in his Amœnitates Exoticæ, by the title of *arbor vernacifera legitima, folio pinnato juglandis, fructu racemoſo ciceris facie*; *i. e.* the true varniſh-tree, with a walnut-tree leaf, and a branching fruit like cicers. It is called by the inhabitants of Japan *ſitz*, or *fiſitz-dsju*, and alſo *urus*, or *urus-noki*. Kæmpfer has alſo deſcribed the wild or ſpurious varniſh-tree, called *faſi-no-ki* by the natives, which he ſays agrees with the other in every part, except that the lobes of the leaves are narrower; but Mr. Miller is of opinion that this is a diſtinct ſpecies, if not a different genus, from the true ſort; and ſays, that the varniſh yielded by it is of little eſteem. The account which the Jeſuits at China have given of the manner in which the varniſh is procured, is as follows: they firſt ſlit the back of the branches of the ſhrub, in different places, with a knife; and thus there flows out a white clammy juice, which is received into wooden veſſels; and when theſe become dry, they tap the ſtems of the ſhrubs near the roots, ſo that all the juice is drawn out of them. The ſhrubs are then cut down to the ground, and from their roots new ſtems ariſe, which in three years will be fit for tapping. The juice turns black when expoſed to the air; it heats without turning ſour; but being of a poiſonous nature, it is dangerous to handle it. This native varniſh wants hardly any preparation; but if any dirt ſhould happen to mix with it, it is cleanſed by being ſtrained through coarſe gauze, put into wooden veſſels, and covered with an oil called *toi*, and a ſkin, in order to prevent its evaporating. In this ſtate it is carried over to China and Japan for ſale. The ſhrub is chiefly cultivated in the provinces of Tſi-kocko and Figo; and the beſt varniſh, according to Kæmpfer's account, is produced about the city Jaſſino; but there is an ordinary ſort of varniſh, called *nam-rak*, brought from Siam, which is collected in the province of Corſania, and in the kingdom of Cambodia, from the tree anacardus, called by the inhabitants *tong*, or *tue-rak*, the fruit of which is called in our ſhops *anacardium*. To collect this liquor, they bore a hole in the trunk, and inſert a tube. By this method they procure as much of it as is ſufficient, not only to varniſh all the utenſils of China, Tonquin, and Japan, but it is even exported in cloſe wooden veſſels to Batavia, and other parts of India. This varniſh, ſays Kæmpfer, is not only ſold quite pure, but likewiſe coloured, with Chineſe native cinnabar, and a kind of red earth, which the Dutch formerly, but now the Chineſe bring them, and alſo with the materials of which they make their common Japan ink. Mr. Ellis has controverted the opinion of Mr. Miller, and endeavoured to ſhew that the American toxicodendron is not the ſame with Kæmpfer's *arbor vernicifera legitima*; alleging, that Kæmpfer's deſcription of the true varniſh-tree does not agree with this toxicodendron; and he inclines to the opinion, that the Carolina pinnated toxicodendron, or poiſon-aſh, is the ſame with the *faſi-no-ki*, or ſpurious varniſh-tree of Kæmpfer. Mr. Ellis alſo thinks it is not improbable, that the varniſh mentioned by Kæmpfer, as obtained from the oriental anacardium, is the ſame with that mentioned by father d'Incarville, in the Phil. Tranſ. vol. xlviii. p. 254, called *tong-yeou*; which is ſo univerſally uſed in China for preſerving and ornamenting their furniture. See this controverſy between Mr. Miller and Mr. Ellis at large, in Phil. Tranſ. vol. xlix. part i. p. 157—166. part ii. p. 806—876. vol. l. p. 430—456. See POISON-*tree*, LINEN, and JAPANNING.

VARNISH, *Brown, for Metals*. See *Black* VARNISH, ſupra.

VARNISH, *Copal Oil*, called in France *vernis martin*, is made by pouring into a well-glazed ſtrong earthern pot, in ſhape reſembling a chocolate pot, and in ſize large enough to hold about a gallon, and made warm, four ounces of Chio or Cyprus turpentine, and when this is diſſolved, eight ounces of finely powdered amber; mingling them well, and ſetting them on the fire for a quarter of an hour; take off the pot, and pour gently into it a pound of copal, finely bruiſed, but not powdered; ſtir the maſs, and add four ounces of Chio turpentine, and a gill of warm turpentine oil; then ſet it on a briſk fire for about half an hour, and taking it off, ſtir the contents well, and add two ounces of the fineſt and whiteſt colophony. Let the pot be put on a very briſk fire, and remain till the whole is diſſolved, and become as fluid as water; let it be removed from the fire, and remain for a few minutes, and then gradually pour in twenty-four ounces of poppy, nut, or linſeed-oil, made drying, and boiling hot, and ſtir the maſs with a deal ſtick. When the gums and oil are thoroughly incorporated, ſet them over the fire for a few minutes, ſtill ſtirring them about, and let them boil once up; and having taken off the pot, pour into it a quart of hot turpentine; ſtir them together, and give them one boil up; take off the pot, and pour into it a pint more of hot turpentine, ſtill ſtirring it well. If the gums are thoroughly melted, and well incorporated, the varniſh is made; which, being cool, is ſtrained through a cloſe cloth into another veſſel, and, if it be too thick, thinned with oil of turpentine, till it becomes of the conſiſtence of linſeed-oil; ſtrain it a ſecond time, bottle it for uſe, and let it ſtand a month, at leaſt, before it is uſed. This varniſh is uſed for coaches, cabinets, &c.; and the piece, whatever it be, after having been varniſhed ſmoothly, and dried in the intervals half a dozen times, and ſuffered thoroughly to dry, muſt be rubbed with a wet coarſe rag, dipped in pumice-ſtone, powdered and ſifted, till the ſtreaks of the bruſh and all blemiſhes are removed. When it is perfectly ſmoothed, waſhed, and dried, the coats of varniſh are to be repeated, for ten or twelve times, till there be a ſufficient body. After having again uſed the powdered pumice-ſtone, and waſhed it off as before, let it be rubbed with fine emery, till the ſurface becomes even and ſmooth as glaſs; then with powder of fine rotten ſtone, till by paſſing the palm of the hand two or three times over the ſame place, you diſcover a gloſs equal to that of glaſs: having dried it clean, dip a rag, or piece of flannel, in ſweet oil, and rub the ſurface a few times over, and clear it off with fine dry powder, flour, or the hand; and a piece of fine flannel, dipped in flour, and rubbed over it, when cleared of the oil, will give it an excellent luſtre. Between every coat of varniſh it will be adviſeable, if the ſubject admits of it, to ſet it in a warm oven; or to heat the varniſhed pieces by ſtoves. See COPAL.

VARNISH, *Gold-coloured*. See LACQUER.

The compoſition of a gold-coloured varniſh, uſed by the Engliſh artiſts for braſs and ſilver, was communicated to ſome of the French academicians in 1720, by Mr. Scarlet, and in 1738 by Mr. Graham, and publiſhed in the volume of the French Memoirs for 1761. It is as follows: Take two ounces of gum lac, two ounces of yellow amber, forty grains of dragon's blood in tears, half a drachm of ſaffron, and forty ounces of good ſpirit of wine: infuſe and digeſt in the uſual manner, and then ſtrain through a linen cloth. The piece to be varniſhed muſt be heated before the liquid is applied: it receives from the varniſh a gold colour, and may be cleaned, when ſullied, with warm water.

VARNISH *for preſerving poliſhed Iron from Ruſt*. See IRON.

Many methods have been uſed for preſerving iron utenſils from ruſt, as animal fats, oils, boiled oil mixed with melted lead, &c. Homberg's ſalve for this purpoſe conſiſts of two pounds of hog's-lard, an ounce of camphor, and as much black lead as will render the mixture of an iron-colour; when this is uſed, the iron muſt be previouſly heated. M. Reaumur has diſcovered a better compoſition for this purpoſe: it is oil, inſpiſſated by being expoſed to the air in flat ſhallow veſſels, ſo as juſt to cover the bottom, mixed with a ſolution of copal in ſpirit of wine: this forms an elegant hard varniſh, which, rubbed on poliſhed iron, made a little hotter than the hand can bear, will cover it with a ſolid, thin, tranſparent coat, without any injury to its colour or appearance. See RUST.

VARNISH, *Lacca*, is made of gum lacca and ſpirit of wine, frequently ſhaken till the gum be diſſolved, then ſtrained, and the clear liquor decanted off.

The lacca ought to be of the kind called ſeed lacca. (See LAC.) Three ounces of this, well purified by repeated ablution of water, dried and powdered groſsly, ſhould be put into a bottle with a pint of rectified ſpirit of wine, ſo as to fill about two-thirds of it, and the bottle placed in a gentle heat; proceeding as above: though for varniſhing ordinary woods, ſhell lacca is often uſed. For this purpoſe, five ounces of the beſt ſhell lacca ſhould be groſsly powdered, and put into a bottle, holding about three pints or two quarts, with one quart of rectified ſpirit of wine; and placed in a gentle heat: the mixture muſt be filtered through a flannel bag. To this varniſh, the colours uſed in varniſh painting may be added, and properly diluted with rectified ſpirit, and kept in phials, or tin veſſels cloſely ſtopped for uſe. But this will not ſtand againſt the weather.

For various preparations of this kind, ſee JAPANNING and LACQUER.

VARNISH, *Maſtich*, is made by putting five ounces of powdered maſtich into a proper bottle, with a pound of ſpirit of turpentine, and ſetting them to boil in balneo Mariæ, till the maſtich be diſſolved, and ſtraining the ſolution through flannel. This varniſh may be converted into a proper varniſh for painting, by grinding one ounce of gum anime on a ſtone with water, till it becomes an impalpable powder; then drying it, and grinding it again with half an ounce of turpentine, and afterwards with the proper colours, and moiſtening it with the maſtich varniſh, till the mixture be of a due conſiſtence for working with the pencil. It muſt then be kept in phials or tin veſſels, and diluted, as there may be occaſion, with ſpirit of turpentine.

VARNISH *for preſerving Paintings*. See PICTURE.

For this purpoſe ſome have recommended the following compoſition: *viz.* half a pound of gum ſandarac; an ounce and a half of Venice turpentine; three-quarters of an ounce of each of the gums anime and copal; half an ounce of maſtich; benzoin, gum elemi, and white reſin, each two drachms, and one pound of rectified ſpirit. The benzoin and gum anime powdered, are put with the Venice turpentine into a phial, with eight ounces of the ſpirit of wine; the copal and reſin powdered are alſo put in a phial with ſix ounces, and the powdered gum elemi, with two ounces of ſpirit of wine. The ſeveral phials are frequently ſhaken, till the gum, &c. are diſſolved; then the ſolutions are ſtrained through a fine linen in one bottle, and when the mixture has ſtood ſome days, it is decanted off clear, and kept in a ſeparate bottle for uſe. Some have ſubſtituted the ſarcocolla for the copal. Another compoſition is formed, by diſſolving maſtich and ſandarac, groſsly powdered,

dered, of each ſix ounces, and Venice turpentine half an ounce, in a quart of highly rectified ſpirit of wine, and ſtraining off the ſolution. If it be required harder, an equal weight of the gums anime and copal may be added, and the quantity of ſpirit of wine doubled. In the uſe of this varniſh, the painting ſhould be thoroughly dry, and it ſhould be ſpread very gently with a pencil. The varniſh ſhould be laid on in a very warm place, or the picture itſelf warmed to a moderate degree, in order to prevent the *chilling* of the varniſh; in which caſe another coat ſhould be added. And, indeed, two or three coats are neceſſary to preſerve the painting, and to bring out a due effect of its colours, if they are in that ſtate called *ſunk in*, occaſioned by the attraction of the cloth on the oils mixed with them. An oil of turpentine varniſh may be added by groſsly powdering maſtich and ſandarac, of each four ounces; two ounces of white reſin; and ſarcocolla, anime, copal, and olibanum, of each one ounce; and putting them into a phial with two pounds of oil of turpentine, ſtopping the phial gently, and placing it in any heat, ſo that the maſs may not boil, and ſtraining off the ſolution for uſe. Or, a varniſh more ſimple, and equally good, may be made by powdering two ounces of ſandarac, maſtich and olibanum, of each an ounce and a half; or three ounces of maſtich, and Venice turpentine half an ounce; and diſſolving them in half a pound of oil of turpentine, and proceeding as before. Handmaid to the Arts, vol. ii. p. 227, &c.

VARNISH *for Paper-hangings*. See PAPER-*Hangings*.

VARNISH *for Printers' Ink*. See PRINTING-*Ink*.

VARNISH, *White*, is uſually made of gum ſandarac and gum maſtich, diſſolved in ſpirits, left to ſettle two days, then ſtrained through a linen cloth, and, after ſtanding ſome time, the clear poured off, and bottled for uſe.

The more curious artiſts diſſolve the two gums ſeparately; and having made a ſeparate varniſh of each, mix them occaſionally, as their work requires a ſtiffer or a ſofter varniſh.

But for the *beſt* white varniſh more gums are required; *viz*. Venice turpentine, gum copal, elemi, benzoin, anime, and white reſin.

Beſides theſe, there are *hard* and *ſoft* varniſhes, or grounds, uſed by the etchers and engravers. See ETCHING.

VARNISH is alſo uſed for a kind of gloſſy coat, with which potter's-ware, Delf-ware, China-ware, &c. are covered, to give them a ſmoothneſs and luſtre. Some preparation of lead is the varniſh ordinarily uſed for the firſt; and earths for the ſecond. See GLAZING and POTTERY.

The true varniſh uſed by the Chineſe and Japaneſe, to give that inimitable luſtre to their porcelain, is one of the grand ſecrets in that manufacture; and is one of the great things wanting, to make Delf and French ware vie with the Chineſe. Several have deſcribed the preparation of it, particularly Kircher: but none ever ſucceeded in the trial. See PORCELAIN and VARNISH, ſupra.

VARNISH is alſo a term applied to the colours which antique medals acquire in the earth.

The value of a medal is heightened by a beauty, which nature alone was able to give, and art has never yet attained to counterfeit: we mean the colour or varniſh with which certain ſoils tinge the medal; ſome with a blue, almoſt as beautiful as that of a turcois; others with an inimitable vermilion colour; and others with a gloſſy ſhining brown, infinitely beyond any of our figures in bronze.

The moſt uſual varniſh, however, is a fine green, which hangs to the moſt delicate ſtrokes without effacing them; much more accurately than the fineſt enamel does on metals. Braſs alone is ſuſceptible of it; for as to ſilver, the green ruſt that gathers on it, always ſpoils it; and it muſt be ſcoured off with vinegar, or lemon juice.

There is alſo a *falſe*, or *modern* varniſh; which the falſifiers of medals give to their counterfeits, to give them the air of antiquity: it is diſcovered by its being ſofter than the natural varniſh, which is as hard as the metal itſelf.

Some lay their ſpurious medals under ground, where they contract the degree of varniſh, that they impoſe on the leſs knowing: others uſe ſal ammoniac, mixed with vinegar; others the acid ſpirit of nitre, &c.

Veins

VEINS, *Metallic* and *Mineral*, in *Geology*, are fiſſures interſecting rocks or ſtrata, filled more or leſs completely with mineral or metallic matter, different from the ſubſtance of the rock. When veins are ſeen on the ſurface interſecting or traverſing a mountain, they have been ſuppoſed to reſemble the veins of animals; but the reſemblance is only ſuperficial, for veins are not tubular, except in a few inſtances; but their thickneſs is ſmall, compared with their length and depth.

Metallic veins are the principal repoſitories of moſt of the metals, except iron and mangancſe, which occur more frequently and abundantly in beds than in veins. The thickneſs of metallic veins varies from a few inches to ſeveral feet or yards: the ſame vein varies alſo in thickneſs in different parts of its courſe, ſometimes contracting to a narrow ſtring of ore, and then expanding again to the width of ſeveral yards. The depth to which they deſcend is unknown, for we believe no inſtance has occurred of a conſiderable vein *being worked out in depth*, though it may ſink too deep to render the operation of the miner profitable; or it may branch off in a number of ſtrings, which are too much intermixed with the rock to be worked to advantage. In caſes where the metallic ores have diſappeared at conſiderable depths, the veins are ſtill continued, though they are filled excluſively with the mineral matter or vein-ſtone which accompanied the ore in the upper part of the rock. Some veins appear to grow wider, and others to contract as they deſcend. The direction of veins downwards inclines more or leſs from the perpendicular; but they ſometimes run for a certain diſtance parallel with the dip of the beds or ſtrata in a mountain, and then ſtrike down through the lower beds.

The length of metallic veins has rarely, if ever, been accurately determined; they have frequently been traced ſeveral miles, but their further progreſs has been concealed by the intervention of valleys, rivers, or accumulations of ſand and alluvial depoſits. Some of the metallic veins in South America have been traced to the diſtance of eighty miles. Large veins generally take a nearly direct line through a country, except where they are turned aſide by croſs veins, or what are called in Cornwall *croſs courſes*: it is alſo remarkable, that the metalliferous veins in England generally run nearly eaſt and weſt, and the croſs courſes north and ſouth. To what cauſe this is owing we are perfectly ignorant. Large metalliferous veins frequently ſend off ſmaller veins, or ſtrings of ore, from their ſides, which penetrate the rock to a conſiderable diſtance on each ſide of the large vein. Veins are ſeldom entirely filled with ore, but ſometimes it extends in a compact maſs from one ſide to the other. More frequently, the ore is intermixed with mineral matter called vein-ſtone, *matrix* or *gangue*: this, according to the rock which it interſects, will be either calcareous ſpar, fluor ſpar, barytes or quartz. The vein-ſtone and the ore are frequently arranged over each other, lining the ſides of the vein with alternate layers of metallic and mineral matter, and filling up the whole vein. In the mines of Cornwall, the ores of copper and tin commonly occur in detached maſſes, which are called *bunches* of ore; and the other parts of the vein, being unproductive, are called *deads*.

The vein is generally ſeparated from the rock which it interſects by a thin layer of mineral matter diſtinct from the vein, and from the rock itſelf, and alſo by a thin lining of clay. Sometimes there are large cavities in veins called *druſes*, which are generally lined with cryſtals. In other inſtances the vein divides, incloſing a piece of rock, which is called the *rider*; but it is obſerved, that the incloſed maſs, or rider, differs in its quality from that of the rock through which the vein paſſes.

The ſuperficial part of a vein generally contains the ore in a decompoſing ſtate; and it frequently happens that the ores in the upper and lower part of the vein are different: thus in Cornwall, blende, or the ſulphuret of zinc, often occupies the uppermoſt part of the vein, to which ſucceeds tin-ſtone, and at a greater depth, copper pyrites. See ZINC, TIN-*Stone*, and COPPER.

When Mr. Pryce wrote his "Mineralogia Cornubienſis," the mines of Cornwall had not been worked to a great depth, for he ſays the richeſt ſtate of a mine for copper was from eighty to one hundred yards deep, and for tin, from forty to one hundred and twenty yards. This account by no means correſponds with the preſent ſtate of the Corniſh mines. The Dolcooth copper-mine, near Redruth, is worked to the depth of four hundred and fifty-ſix yards, and is very productive at that depth.

Veins generally decline from the perpendicular, and deſcend into the earth obliquely. The ſides, or, as they are called, the walls or cheeks of the vein, are differently denominated, the upper ſide being called the *hanging-ſide*, the *up-cheek*, or *hanger*; and the under ſide, the *hading-ſide*, the *down-cheek*, or the *ledger*. The veins we have been deſcribing are called *rake* veins in ſome parts of England, and in Cornwall, they are denominated *lodes*; which ſee. Theſe metalliferous veins have commonly the ſame direction, or nearly ſo, in the ſame diſtrict, and the veins which croſs them are generally unproductive, or contain metallic ores of a different kind. They are called *croſs courſes*, or north and ſouth veins.

Metalliferous rake-veins interſect moſt of the mountains called primary, ſuch as granite, gneiſs, and mica-ſlate. (See GRANITE, &c.) But they are more abundant in ſlate-rocks than in rocks of granite or porphyry. (See GRANITE, SLATE, and PORPHYRY.) They alſo interſect the rocks of tranſition and mountain lime-ſtone, which reſt upon ſlate, or alternate with it; but they rarely riſe into the ſecondary ſtrata which contains coal. This fact ſeems to prove that veins were formed prior to the depoſition of the upper ſecondary ſtrata. When a metallic vein in its deſcent paſſes through different kinds of rock, it is frequently obſerved that the products of the vein vary in each bed; and when it

paſſes through regularly ſtratified beds of the ſame rock, there are particular ſtrata in which the veins are always found moſt productive, and theſe in the north of England are called *bearing meaſures*. If the nature of the rock ſeems to have produced a change in the quality of the ore, it is no leſs remarkable that the rock itſelf is alſo frequently changed or decompoſed in the immediate vicinity of a vein. This change is more apparent in ſome rocks than in others, particularly in granite, ſienite, gneiſs, mica-ſlate, argillaceous ſchiſtus or ſlate, and porphyry. In ſuch inſtances, according to Werner, it is only one of the component parts of the rock that is decompoſed, either the felſpar, the hornblende, or the mica, but never the quartz. This change ſometimes extends to a conſiderable diſtance on each ſide of the vein, even to a fathom or more; it extends farther in ſome places than in others, and is moſt general in thoſe parts where the vein contains ſulphur. Sometimes this change in the rock may be perceived ſo far, that it ſerves as a guide to the miner; and in following a ſterile vein, when he comes to a place where the rock is decompoſed, he concludes that the metallic ore will ſoon be found. In Cornwall, the felſpar is frequently changed in the vicinity of a vein, and tin-ſtone is ſometimes diſſeminated through the rock to ſome diſtance on each ſide of it.

The croſs courſes or veins which interſect the metalliferous veins, frequently occaſion a conſiderable derangement in the poſition of metalliferous veins, and, what is ſtill more remarkable, occaſion a change in the quantity or quality of their contents. When a vein is cut through by another, either in its line of bearing along a country, or croſſes it by declining in a different direction, the vein which is cut through is ſuppoſed to be of more ancient formation than the vein which croſſes and cuts through it; but it may be doubted, from various circumſtances, whether many of theſe veins were not formed at the ſame time with the rock itſelf, or were fiſſures paſſing through the rock in different directions, into which the various metallic ſubſtances were ſecreted, during its conſolidation. To form a more diſtinct idea of the ſtructure of a vein and its interſection by croſs courſes, we refer to *Plate* IV. *Geology*. *Fig*. 4. *a a* repreſent a rake-vein deſcending obliquely; *b b*, the rock; *c*, *c*, the walls or cheeks of the vein; *d*, an interpoſing piece of rock, called the rider; *e*, *e*, *e*, the diviſion of the vein into numerous ſmall veins or ſtrings of ore. If the ſpace at *d*, which is ſuppoſed to be filled with rock, were empty, or filled with water, it would conſtitute what is called a druſe; and it is in theſe cavities or druſes that all the moſt beautiful and regular cryſtallizations of the mine occur. *Fig*. 5. repreſents the ſection of a rock containing a metallic vein cut through, and diſplaced by croſs courſes or veins of another metal; *a a a* is a vein which appears to have been once continuous, and contains tin; *b*, *b*, *b*, repreſent different veins of copper, which cut through the former, and have upheaved the lower part, and brought them nearer the ſurface. In *Plate* II. *Geology*, *fig*. 10. repreſents the ground plan or horizontal ſection of a plot of ground traverſed by a vein and a croſs courſe; E.W. repreſent the eaſt and weſt ſides of the ground. It is in this direction the vein *a a* paſſes, but it is cut through by the croſs vein *b b*, which has carried the weſtern ſide of the vein and the ground along with it conſiderably to the north of its original poſition. Such a fracture and removal of the vein can only be conceived to have taken place by a lateral or horizontal motion of a portion of the ground. Such a motion has been frequently obſerved during violent earthquakes. For though the ground is heaved upwards, the greater reſiſtance which certain parts offer to this motion muſt occaſion a lateral preſſure on other parts of the earth's ſurface, and to ſuch a preſſure we muſt alſo refer the remarkable contortions of the coal ſtrata near Valenciennes. See *Plate* II. *fig*. 9.

Metallic veins frequently occaſion a diſplacement of the ſtrata when they paſs through regularly ſtratified rocks; and it is obſerved, that when this diſplacement is conſiderable, ſo as to bring a bed of lime-ſtone on the ſame level with a bed of ſand-ſtone or ſhale, the vein is never ſo productive as when the oppoſite ſides or walls of the vein are in the ſame kind of rock. See *Plate* II. *Geology*, *fig*. 8. where the different ſtrata *a*, *b*, *c*, *d*, *e*, *f*, *g*, repreſent different ſtrata on each ſide of a vein or fault. If *d*, *d*, are ſuppoſed to repreſent parts of a bed of lime-ſtone broken by the vein, and *g g* a bed of ſand-ſtone below the lime-ſtone, but brought on the ſame level with it by the upheaving of the ſtrata,—in that part of the vein where the lime-ſtone, *d*, and the ſand-ſtone, *g*, form the walls oppoſite to each other, the vein will be unproductive, though in other parts of the diſtrict, when the vein paſſes through the ſame bed of lime-ſtone, on each ſide of it, at the ſame level, it will be remarkably productive. Theſe facts may be commonly obſerved in the mining diſtricts of the weſtern parts of Northumberland and Durham, where the ſtrata conſiſt of different beds of mountain lime-ſtone, ſand-ſtone, and ſhale. See STRATA, under which article the ſucceſſion of the different beds is enumerated.

As croſs veins generally diſplace and injure the quality of veins, on the contrary, when eaſt and weſt veins in a diſtrict meet, by a ſlight variation in their direction or dip, the part where they join is frequently very rich in ore; and where a number of metallic veins croſs each other at the ſame place, they frequently produce a large irregular conical maſs of ore of vaſt extent, from which the different veins diverge, like radii from a common centre. The main ſhaft of ſuch a vein, which Mr. Williams, in his Mineral Kingdom, calls an *accumulated* vein, "reſembles," he ſays, "the inſide of a glaſs-houſe; and the vaſt capacity of this vein is frequently ſtored with a rich body of metallic ore, often imbedded in ſoft mineral ſoils; but the veins and branches which join and diverge reſemble rake-veins, or perpendicular mineral fiſſures. When the ore is worked out of an accumulated vein, it exhibits a frightful gulf, ſometimes fifty or ſixty feet wide below, and is often worked down to a great depth from the ſurface." A number of theſe accumulated veins have been worked at Pike-Law, in the county of Durham. Croſs courſes ſometimes contain ore to a ſmall diſtance from their junction with metallic veins, and in other ſituations they become ſo rich as to be worked with advantage. The Botallock mine, on the ſea-coaſt near St. Juſt, in Cornwall, offers a ſtriking illuſtration of this, though we believe its ſtructure has not been generally known or underſtood. The vein which is worked is a north and ſouth vein, varying in width from nine to twelve feet, and extending under the ſea. The vein-ſtone is quartz, with a ſmall quantity of fluor ſpar. It is found to contain ore of copper and tin only in thoſe parts where the eaſt and weſt veins enter it, and for thirty or forty fathoms on each ſide of the junction. This mine produces the richeſt ore of copper in Cornwall, the grey ſulphuret yielding twenty *per cent*. of this metal. It is deſerving notice, that the metalliferous veins which enter this lode on the eaſt ſide and render it productive, have never been found on the weſt ſide, ſo that they appear to terminate in it. The rock near the great north and ſouth vein is a ſoft killas or ſlate, but beyond this it is a very indurated flinty ſlate. This vein may properly be conſidered as a croſs courſe, rendered rich in ore in various parts by a number of ſmall veins which fall into it, like brooks into a large river

where they are loſt. The ſituation of this mine is truly remarkable, at the foot of a precipitous cliff that overhangs the Atlantic ocean. If ever a ſpot ſeemed to bid defiance to the efforts of the miner, it was this. At the very commencement of his labours, he was required to lower an immenſe ſteam-engine down a precipice of more than two hundred feet, with a view of extending his operations under the bed of the ſea, where the workings are at preſent continued for ſeventy fathoms in length and ſixty-five fathoms in depth. In theſe caverns of darkneſs, many human beings for a ſmall pittance, and that even of an uncertain amount, are conſtantly digging for ore, regardleſs of the horrors which ſurround them, and of the roar of the Atlantic ocean, whoſe boiſterous waves are inceſſantly rolling over their heads. In ſome places the ſea actually penetrates through; and it is worthy of obſervation, that the water is deprived of a great portion of its ſalts; but whether this ariſes from filtration, or whether ſome portion of the freſh water from the land percolated through ſubterranean fiſſures in the rocks, we could not aſcertain when we viſited this ſingular mine. If the filtration be more abundant after heavy rains, it would prove the intermixture of rain-water. The thin croſs courſes filled with clay called flucan, heave the eaſt and weſt veins, and alſo hold up the water. The vein which is rich in ore on one ſide of the flucan, will be poor on the other ſide. This fact, which we believe has not been ſufficiently noticed, is well deſerving attention, and would indicate that the preſence of water affected the contents of veins.

Some veins contain little diverſity in the nature of their contents, being filled principally with one kind of ore or vein-ſtone. Other veins contain a great variety of minerals, without any apparent regularity of arrangement: there are alſo numerous veins which have a regular ſtructure, the different minerals being arranged in parallel layers, coating each other: the ſame ſucceſſion of different minerals occur on each ſide and meet in the middle, filling up the vein, or ſometimes leaving an empty ſpace between. Thus calcareous ſpar, fluor ſpar, barytic ſpar, lead-ore, blende, and grey copper-ore, form different layers over each other in the ſame ſucceſſion on each ſide of the vein. In the Botallock mine, before deſcribed, copper-ore is frequently found lining each ſide of the vein, and this is covered by tin; but in other parts of the mine the tin covers the walls, and is ſucceeded by copper.

Irregular Veins.—Beſides rake-veins, which may be conſidered as regular, there are other veins which preſent a great variety of ſtructure, and are called *bellies*, *pipes*, &c. according to their form. If a rake-vein be regarded as a tubular maſs of mineral matter interſecting mountains; if this vein become irregular, and have its ſides cloſed, or, as the miners call, *twitched in*, it forms what they denominate a pipe-vein, or maſs of ore and vein-ſtone ſometimes of a tubular ſhape, deſcending to a conſiderable diſtance like a pipe. In other inſtances, the ſides are cloſed in both above and below, as well as on the ſides, incloſing what the miners call a *belly*, or maſs of ore of conſiderable magnitude. Sometimes a ſmall rib of ore is continued through that part of the rock where the ſides of the vein are twitched in, until the vein expands again and produces another maſs of ore. In ſome inſtances there is no ore between, a rib of vein-ſtone or rider of clay being carried through the narrow part or *twitch* of the vein, but many of theſe twitches contain neither ore, clay, nor rider. In ſuch caſes, it becomes exceedingly difficult to follow the vein through the rock, to where it opens out again.

The veins in general do not cloſe ſuddenly, but the ſides gradually approach each other, and the ore terminates in the form of a wedge at the *twitch*.

Theſe contractions or twitches are of various lengths, and no miner can tell, when the vein is ſo ſqueezed in, how many fathoms he muſt paſs through before it opens again, unleſs the ſame twitch has before been cut through above or below the part where he is working. The intervening ſpace between two maſſes of ore is called a *bar*, and ſometimes extends ten, twenty, or even a hundred fathoms or more; and when it is cut through, the ore makes its appearance, and begins gradually to widen and form another maſs or belly. When one of theſe bellies of ore proves pure and ſolid, it generally happens that all the contiguous bellies prove ſo in the ſame vein. According to Mr. Forſter, inſtances have been known of eight hundred *bings* of ore being raiſed by ſix miners from one of theſe bellies in the ſpace of nine weeks.

When the matrix in theſe large bellies of ore is ſoft, the ore is generally found in a globular form, more or leſs irregularly imbedded in the ſoft materials, and theſe globular maſſes of ore are of various dimenſions. It is no uncommon thing to find the ſoft openings in this kind of vein ſwell to an enormous width, ſo as to make it difficult to find the real ſides of the vein. Working theſe veins is the moſt difficult part of mining, as there is no proceeding a foot without advancing timbers as far as they go, in the form of a paſſage in a houſe, compoſed of two ſide-poſts, a lintel and a ſole. The miners ſtand within this ſquare frame, where they work and erect more timber as they proceed. It frequently happens that the ore is ſo plentiful and rich in this kind of metallic repoſitory, as abundantly to compenſate for all the labour and expence.

Flat Veins and Beds.—When a vein runs parallel with the ſtrata, it is called a flat vein. If the ſtrata are ſoft, and the metallic matter is widely diſtributed, ſuch veins do not differ from beds, being regular beds or ſtrata impregnated with metallic matter. When flat veins run between hard ſtrata, they are alſo liable to contractions, or *twitches*, and again expand, forming *pipes* or tubular maſſes of ore, which extend in an inclined poſition, having the ſame dip as the ſtrata. Flat veins may be diſtinguiſhed from beds by this character; proper flat veins appear to be openings between the ſtrata which have been filled with metallic matter from a rake-vein, or are at leaſt connected with it, as they ſeldom are productive of ore, except in the vicinity of the vein; whereas beds are regular ſtrata, having the ſame elevations and depreſſions as the other ſtrata in a mountain, but containing metallic matter more or leſs abundantly ſcattered through them. Iron ores and ores of mangneſe frequently occur in beds, forming regular parts or layers of the mountain. Other metallic ores, which occur leſs frequently and abundantly in beds, are, we believe, for the moſt part veins which have taken the courſe of the ſofter beds and diſtributed their contents through them. It is well known, that when a vein deſcends through ſtrata of different kinds of rock, it grows wider in the ſoft ſtrata, and contracts in the harder beds of rock.

The metalliferous beds in Cumberland appear, in many inſtances, to be ſoft beds, rendered productive of ore by a number of ſmall veins running through them. There are few metallic beds in England, except in that county. Mangneſe occurs in beds in red ſand-ſtone in the vicinity of Exeter, but the metallic matter decreaſes as the beds dip from the ſurface. Metallic beds, in primary countries, occur moſt frequently among the ſchiſtoſe mountains, compoſed of gneiſs, mica-ſlate, and ſlate. (See ROCK.) It is obſerved, that the ores and minerals which occur in beds are ſeldom cryſtallized, as theſe beds contain few druſes or

cavities to admit the formation of cryſtals. The minerals in beds are accompanied with garnet, actinolite, and hornblende, which never occur in rake-veins. See GARNET, &c.

Stock-worke.—When a rock is croſſed and penetrated by a great number of ſmall veins in every direction, the whole maſs is worked as an ore, and is called by the Germans a ſtock-worke, or werke, the rock being afterwards ſeparated from the ore by pounding and waſhing, in the ſame manner as the vein-ſtone is cleared from the ore in other mines. When the ore is diſſeminated in particles through the rock, ſuch rocks are alſo worked for the ore when it exiſts in ſufficient quantity. In ſome inſtances, maſſes of ore of great magnitude are found imbedded in rocks, without any apparent connection with veins, which maſſes muſt have been formed at the ſame time with the rock itſelf.

Rocks and ſtrata are ſometimes penetrated by metallic ſalts or oxyds, diffuſed through the maſs in the ſame manner as we frequently obſerve ſtrata of ſand-ſtone abounding with the red oxyd of iron. Where the metals are valuable, ſuch impregnated rocks or ſtrata are ſometimes worked as ores. At Alderley Edge, a hill near Macclesfield, in Cheſhire, the ſand-ſtone, which is in ſome parts a kind of breccia, is impregnated with the black oxyd of cobalt, with the carbonate and oxyd of copper, and with particles of ſulphuret and carbonate of lead, and has formerly been worked for the lead and copper, and more recently for the cobalt. Mr. Williams, in his "Natural Hiſtory of the Mineral Kingdom," deſcribes a ſingular ſtratum of ſtone near Loſſymouth, in the ſhire of Moray, of about eight feet thick, which is compoſed of ſeveral ſpecies of hard and fine ſtones of various beautiful colours. "This ſtratum is a kind of pudding-ſtone, in the compoſition of which there is blended about an eighth part of good blue lead-ore or galena.

"This curious bed of ſtone is nearly horizontal, but dips away with an eaſy ſlope towards the north of the Moray Frith. The lead is found in larger and ſmaller grains and flowers, blended through the whole body and compoſition of the ſtone, in the ſame manner as the ſmall maſſes of agates and coloured cryſtals, and other ſpecies of ſtone, are found blended through the whole body of the ſtratum."

Where metallic ore is thus intermixed with fragments of rock forming a conglomerate or breccia, it may probably be referred to the ſame kind of metallic repoſitory as ſtreamworks, (ſee STREAM-*Works*,) in which particles and maſſes of ore are intermixed with looſe pebbles and ſand, forming beds at the bottom of valleys, or on the ſea-ſhore, the metallic matter, as well as the pebbles, being derived from the diſintegration of rocks containing metallic veins; but in the inſtance cited by Mr. Williams, the parts have become united, forming a ſolid ſtratum.

The manner in which metallic veins were filled with ore has greatly divided the opinions of geologiſts. George Agricola, a Saxon, who died in 1555, appears to have been the firſt writer who had any diſtinct knowledge of the ſtructure of metallic veins, which he publiſhed in a work entitled "De Rê Metallica," and another work entitled "Bermannus." His theory of veins is in ſome reſpects ſimilar to that of Werner, which has lately excited much attention. According to Agricola, the rents or fiſſures which are filled with metallic matter were partly formed at the ſame time with the rocks themſelves, and partly afterwards, by the waters penetrating the ſofter parts; ſo that where there has been a larger quantity of water, or where the ſubſtance of the rock has been much ſoftened, there the largeſt fiſſures occur. With reſpect to the earths and ſtones found in veins, he conceives the former to have been detached from the rocks and carried into the veins by water; the latter he conſiders as ariſing from the earthy matter, hardened partly by change of temperature and partly by a lapidific juice. Minerals and metals he regards as being depoſited from a ſolution in water, containing the earthy parts intimately mixed and combined with it in certain proportions. The ſolution of theſe mineral ſubſtances he conceives to have been greatly promoted by heat, on the abſtraction of which they aſſumed their preſent ſolid form; the precious metals being the reſult of a more pure and perfect ſolution.

Becher, in his "Phyſica-Subterranea," publiſhed in 1669, aſcribes the formation of metals and minerals to certain ſubterranean vapours which ariſe from the bowels of the earth, and penetrating the ſubſtance of veins, produce a peculiar change in the earthy or ſtony matter they meet with. He regards the earth as a hollow body, filled with clay, water, ſulphureous and bituminous ſubſtances, from which ariſe certain exhalations that form the metals. The celebrated German phyſician Stahl, conſiders veins, as well as the ſubſtances they contain, to have been formed at the ſame time with the earth itſelf, and of courſe as being contemporaneous with the rocks they interſect; but he is diſpoſed to attribute ſome effect to the action of air and other cauſes.

Henkel, in his "Pyritologia," has given an ingenious theory of the formation of metallic veins, which has been adopted, with certain modifications, by ſome later geologiſts: he attributes the formation of ores to a peculiar exhalation produced and engendered by fermentation, ſuppoſed by him to take place in the interior of rocks. The baſis of each ore and mineral he ſuppoſes to exiſt in the ſubſtance of the rock, and by a peculiar proceſs of nature it is matured and converted into the metal. He does not venture to aſcertain the nature of theſe baſes, but in one paſſage he treats of ſubtle earths, in another of mercurial, arſenical, and ſulphureous parts. Theſe three laſt he probably conſidered as conſtituent parts, and the metals as compounds. Air, water, and fire, are ſubſtances, according to this mineralogiſt, of which Nature avails herſelf in the formation of metals. He alſo ſuppoſes certain kinds of earths and ſtones to exiſt, which ſerve as the matrix for others, and which are indiſpenſably neceſſary in the formation of minerals.

Zimmerman, the pupil of Henkel, is the firſt mineralogiſt who conſiders veins to have been formed by a transformation of the ſubſtance of the rock. Minerals, he ſays, are undoubtedly formed in the rock; but daily experience ſhews that the rock is not of itſelf capable of forming a metal, for were the mineralizing principle capable of converting it into a metal, we ſhould find whole mountains which had undergone this change. But this change is only met with in certain directions, where the part of a rock, being thus transformed, conſtitutes veins. Theſe veins, when they have not ſuffered an entire change, or when they do not contain perfect metals, are ſtill of a different nature from the reſt of the rock. An attentive examination will ſhew that they are of a decompoſed and friable nature, appearing to have a tendency to return to this natural earthy ſtate, from which we may conclude that theſe veins were originally the ſame as the rock, but that their texture had been altered and decompoſed by ſome particular ſaline ſubſtance, which penetrated the rents and fiſſures, and had rendered them fit to be transformed into minerals.

Before noticing the theory of Von Oppel, which has ſince been adopted by Werner, we ſhall ſtate the opinions of thoſe geologiſts who, with Henkel and Zimmerman, ſuppoſe that veins have been filled by local cauſes which may ſtill continue to operate; whereas Von Oppel and Werner conceive that they were formed by a general cauſe, the operation of which ceaſed before the preſent ſtate of the globe. Lehman, in his

treatise on the matrices of metals, published in 1753, says, "the veins which we find in mines appear to be only the branches and shoots of an immense trunk, which is placed at a prodigious depth in the bowels of the earth, but in consequence of its great depth we have not been able to reach the trunk. The large veins are its principal branches, and the inferior ones the twigs. What I have said," he adds, "will not appear incredible, when we consider that the bowels of the earth are, according to every observation, the workhouse where Nature carries on the manufacture of the metals; that, from the beginning of the world, she has been working at, and elaborating their primitive particles; that these particles issue forth, in the form of vapours and exhalations, to the surface of the globe through rents, in the same manner as the sap rises and circulates through vegetables by means of the vessels and fibres of which they are composed."

The latter part of the theory of Lehman, which supposes that changes are now taking place in the interior of the globe, by which metallic ores are still forming, has been supported by many geologists, who have had opportunities of extensive observation. Mr. Von Trebra, sub-director of mines in Saxony, in his work entitled "Observations on the Interior of Mountains," advances a theory nearly similar to that of Zimmerman, and agreeing in part with Lehman. From the third letter of that work we make the following extract.

"In explaining the phenomena which are observable in the interior of mountains (it must however be remembered, that I do not include such as are evidently of volcanic origin), I do not avail myself of those great causes which, by their magnitude, the suddenness of their action, and by their effects, produce sudden changes which take place under our eyes, such as subterranean fires, earthquakes, and the like. I refer these phenomena to natural causes, which, though less evident and slower in their operation, are no less certain of producing a radical transformation. Of this kind are putrefaction and fermentation. It is of little consequence by what name we distinguish this peculiar action exerted by Nature in the mineral kingdom; it consists in an intestine motion in the central parts of the globe, and appears to be produced by water combined with heat in different degrees of intensity. I observe such changes still going on, and can conceive them to continue so long as the same series of operations exist in nature. I am persuaded that there is constantly going on in our mountains a variety of transformations, compositions and decompositions, which not only take place at present, but will continue to the end of time.

"Fermentation, if I may be allowed to call by that name this quality which acts by insensible degrees, produces the most perfect transformations in the bowels of the earth; fermentation I say may, according to my theory, alter the entire mass of a mountain; it may convert granite into gneiss, as this last only differs from the former in its structure, which is slaty or schistose; gneiss indeed has no other distinctive character than its structure, namely, the regularity and parallelism of its beds, and in some places a decomposed felspar approaching to clay. This fermentation may also convert greywacke into an argillaceous schist, which last may again by induration become jasper, when this process is either diminished or stopt. By it, also, quartz may be converted into clay, calcareous substances into quartz, and the whole mass of a mountain into inflammable or saline matter, or even into ores, metals, or semimetals. To it I ascribe the power of producing, preserving, and continuing to form the different beds and mineral repositories, which are found both in primitive and flœtz mountains: finally, the effects which the waters produce in filtering from above to below, and which in their passage through the different rocks may undergo some peculiar modification, appear to me the principal cause why this fermentation may act with more force in one part of the same mountain than in another."

Patrin, a celebrated French mineralogist, considers the changes taking place in the mineral kingdom, as effected by a process somewhat similar to secretion in the animal and vegetable kingdoms, and ascribes a kind of mineral life to the earth itself, differing perhaps as much from vegetable life as the latter differs from that of animals. According to this theory, each kind of mineral substance is capable of converting masses of mineral matter into its own peculiar nature, as animals convert their aliment into flesh and blood. Whatever may be thought of this theory, we believe that those who are most practically conversant with the various phenomena and transmutations that occur in mines, will readily admit that many changes are taking place, which cannot be explained on any known chemical or mechanical principles, and which bear a strong resemblance in their effects to the process of secretion. Nor can it, even in the present state of chemical science, appear improbable that the different earths and metals may be converted into each other by natural processes. The different beds of rock intersected by metallic veins, are themselves metallic substances combined with oxygen; or, in other words, all the rocks and strata which form the earthy parts of the globe, consist of oxygen combined with metallic bases; and as these metallic bases may perhaps be compounded of the same elementary parts united in different proportions, the transmutation of one earth or metal into another, may be effected by a simple change in the arrangement of the elementary molecules.

The theory of veins proposed by Von Oppel, and in part supported and extended by Werner, supposes veins to have been fissures originally formed by the desiccation of mountains, and the shrinking in of the mass. These fissures, being open at the top, were afterwards filled with their contents by metallic solutions poured in from above. Mountains, according to Werner, have been formed by a successive accumulation of different beds and layers, placed or heaped over one another. "The substance of these beds was at first wet, and possessed little solidity; so that when the accumulation of matter had attained a certain height, the mass of the mountain yielded to its weight, and must consequently have sunk and cracked. As the waters which assisted in supporting the mass began to retire, and lower their former level, these masses then lost their support, and yielded to the action of their weight, opening, and falling to the side where the least resistance was opposed. The shrinking of the mass of a mountain produced by desiccation, and still more the fractures by earthquakes, and other similar causes, may also have contributed to the formation of fissures.

"The same precipitation, which in the humid way formed the strata and beds of rock, furnished and produced the *substance of veins*. This took place when the solution, from which the precipitation was formed, covered the existing rents, which were as yet wholly or partially empty, and open in the upper part. Veins, whether considered as rents, or as the substance constituting the vein, have been produced at very different times; and the antiquity or relative age of each can be easily determined."

Such, in Werner's own words, are the great outlines of his theory, a theory which we conceive to be decidedly opposed by all the most striking appearances existing in the mineral kingdom, and equally opposed to the simplest known and acknowledged laws of nature. If metallic veins were once open fissures, filled by precipitations from a solu-

tion that covered the whole globe, with the higheſt mountains in which metallic veins are found; it is obvious that theſe metallic precipitations would be moſt conſiderable in the lower parts of the ſurface, in valleys and plains, where the fluid muſt have been much deeper than on the ſummits and ſides of mountains. We ought, therefore, to find thick beds of metallic matter covering and incruſting the low and level parts of the globe; but nothing is more rare than to find beds of metallic matter in low plains. Where beds of metallic matter exiſt, it is always in comparatively high countries, abounding in veins; and it is much more probable that the beds and veins were formed by local cauſes, and not from a ſolvent covering the whole globe. The metallic parts of this metalliferous ocean muſt have poſſeſſed the greateſt ſpecific gravity, and inſtead of floating on the top of the fluid, to be depoſited in the fiſſures of lofty mountains, it would have deſcended by the laws of gravity, forming cruſts of different degrees of thickneſs from the bottom to the top, increaſing downward. The reverſe of this is the fact. It is principally in alpine diſtricts, and at enormous heights, that metallic matter is accumulated in the greateſt abundance. It is in the heights of the Cordilleras of Peru that the productive mines of Potoſi are ſituated: it is in the ſame chain of mountains, more than 14,000 feet above the level of the ſea, that the prodigious maſs of mercurial ores is found at Guanca Velica, where, in the ſpace of two centuries, more than 15,000 quintals of this metal have been procured.

But the facts moſt oppoſed to the theory of Werner are thoſe which we have ſtated, namely, that when a metallic vein paſſes through different ſtrata, the mineral ſubſtances it contains generally vary in each ſtratum, either in kind or quality. Sometimes an entire change takes place, as from tin to copper or lead; in other inſtances, the vein will contain the ſame kind of ore in the different ſtrata, but it will be invariably richer or poorer in ſome of the ſtrata than in others, and there will be certain ſtrata in which ſcarcely any ore occurs. Very frequently where the ſame kind of metallic matter is contained in the vein, it will be mineralized or combined with different ſubſtances, as the vein paſſes through different beds: thus we find a metallic ſulphuret more prevalent in one part, and a metallic ſalt or oxyd in another part of the vein.

In Derbyſhire, where the veins of lead paſs through different beds of mountain lime-ſtone, which alternates with beds of baſaltic amygdaloid, provincially called toad-ſtone, it is found that the vein ſcarcely ever contains lead as it paſſes through the toad-ſtone, where it is always much narrower, and in ſome places appears to be entirely cut off by it; but on ſinking into the under beds of lime-ſtone, the vein is found again, and is as productive as in the upper beds. Where the vein can be traced through the toad-ſtone, it contains calcareous ſpar, and ſometimes a few particles of lead-ore. If veins had been filled from above by metallic ſolutions, it is impoſſible to conceive that the nature of the rock could change the quality of the ore; much leſs could the ore diſappear in one ſtratum, and appear again in a ſtratum below it. Profeſſor Jameſon, in a paper publiſhed in the Memoirs of the Wernerian Society, has attempted to explain the difficulty preſented by the interruption of the veins in Derbyſhire, on the ſuppoſition that the different beds of lime-ſtone and toad-ſtone, together with the metallic veins, were contemporaneous, and that the toad-ſtone cut through the veins at the period of their formation. On this hypotheſis, Mr. Bakewell, in his Introduction to Geology, remarks: "The exiſtence of different organic remains in the upper and lower beds of the mountain lime-ſtone in Derbyſhire, precludes the poſſibility of theſe beds having been all formed at the ſame time. The zoophytes in the lower beds of rock could not be living and co-exiſtent with the ſhell-fiſh in the upper, nor with the vegetables, the remains of which are occaſionally found in the ſand-ſtone that covers the whole, and into which the veins ſometimes ſhoot. Cuvier has well obſerved, that the exiſtence of different organic remains in the upper and lower ſtrata offers inconteſtible proofs that they were formed in ſucceſſion over each other." In point of fact alſo, the veins are not always cut off by the toad-ſtone; but they are never productive of ore, where they paſs through it, except in very ſmall particles.

Theſe facts are not leſs oppoſed to the igneous theory of metallic veins than to that of Werner. If metallic veins had been filled with their contents by the operation of ſubterranean fire, which cracked the ſurface, and injected the metallic matter in a ſtate of fuſion, it is impoſſible to conceive that the nature of the rock, through which the veins paſs, could have produced any material change in the quality of the ore. Metallic ores may, in ſome inſtances, have been formed ſlowly by exhalations from ſubterranean fires; as ſpecular iron-ore, and even gold, has been found in the craters of volcanoes; and the phenomena, preſented by the lava which deſtroyed Torre del Grecco in 1794, indicate the manner in which ſuch ores are formed. The lava had buried entire houſes for more than twelve months, at the latter end of which time it had conſiderably cooled; and when the houſes were opened, pieces of iron were found converted into a ſtate of black, red, and magnetic oxyds, having the hollow parts and interſtices filled with a browniſh-red tranſparent oxyd of iron, and with ſpecular iron-ore. In the articles made of iron, which had undergone this change, the external form was ſcarcely altered, which evinces that the cryſtals had been produced by ſublimation. Copper articles were changed into cryſtallized red oxyd of copper, and red oxyd with green and blue carbonate. From the abſence of metallic ſulphurets, it is inferred that the lava contained little, if any, ſulphur. Theſe changes ſhew that metallic matter may be ſublimed and converted into the ſtate of ore by ſubterranean heat, at a much lower degree of temperature than has been ſuppoſed.

There is a circumſtance on which thoſe who contend for the aqueous formation of metallic veins have laid much ſtreſs. In ſome inſtances, rounded pieces of ſtone, apparently reſembling water-worn pebbles, have been found in mines at a conſiderable depth; but as many veins contain hollow ſpaces, through which water is continually running, the formation of pebbles might admit of a ſatisfactory explanation, without ſuppoſing that theſe pebbles had fallen in from above. The pebbles which we have ſeen of this kind, from the mines in Cornwall, are all of a chlorite ſchiſtus, and the form oblate, preſenting the appearance which may frequently be obſerved in rocks of the ſame kind. It is in all probability an original formation, and not a breccia from pre-exiſting rocks.

There is another circumſtance which appears to have eſcaped the attention of geologiſts. The water in the mines of Cornwall, particularly in the vicinity of copper veins, has a temperature conſiderably above that of the natural temperature of the earth: it is ſaid to be at 70° Fahrenheit; and the working miners, from its ſenſible warmth, can predict with certainty the vicinity of a copper vein. The increaſe of temperature, if any, in the vicinity of tin veins is leſs ſenſible.

From hence, as well as from various appearances in mines, we are led to infer that there are certain chemical changes

now going on in the interior of the earth; and it is from a more enlarged acquaintance with thefe phenomena, that we can alone expect to obtain a fatisfactory theory of the formation of metallic veins.

The following is a fummary account of the rocks and fituations in which metallic ores are generally found.

Platina, and the recently difcovered metals, palladium, rhodium, ofmium, and iridium, have not been hitherto found in veins, but in the fands of rivers. The four latter metals are found as alloys in the grains of platina. See PLATINA, PALLADIUM, &c.

Gold and filver are found in veins, and differminated in primary and tranfition rocks, in porphyry, fienite, and the lower fand-ftone. Gold has been occafionally difcovered in coal, and is very abundantly differminated in the fands of fome rivers. See GOLD and SILVER.

Mercury is found in flate, in lime-ftone, and in fecondary ftrata. See MERCURY.

Copper occurs in veins and beds in primary and tranfition rocks, in porphyry and fienite, and occafionally in fand-ftone. Maffes of native copper, of large fize, are found on the furface of the ground, in the interior of North America. See COPPER.

Lead and zinc occur in veins, and differminated in primary and tranfition rocks, except trap and ferpentine, in the lower fecondary ftrata, and in porphyry and fienite. See LEAD and ZINC.

Antimony occurs in veins in primary and tranfition mountains, except trap and ferpentine.

Bifmuth, cobalt, and nickel, occur in primary and tranfition mountains, except lime-ftone, trap, and ferpentine. Cobalt and nickel alfo occur in tranfition mountains, and in fand-ftone. See BISMUTH, &c.

Arfenic occurs in veins, either as a fulphuret or mineralizer of other metals, in primary and tranfition mountains, and in porphyry. See ARSENIC.

Tellurium occurs in veins in porphyry, combined with gold. See TELLURIUM *Mines*.

Manganefe occurs in beds and veins in primary and tranfition mountains, and in beds, and differminated in red fand-ftone. See MANGANESE.

Molybdena, tungften, and titanium, occur in granite, gneifs, mica-flate, and argillaceous fchiftus. Thefe metals, with chromium and cerium, are very rare, and can only be reduced to the metallic ftate with great difficulty. See MOLYBDENA, &c.

Mineral veins differ from metallic veins, being deftitute of ores, and filled with the fame fubftances which compofe entire rocks, or with earthy minerals.

Quartz veins (fee QUARTZ) refemble in their ftructure and pofition many metallic veins; and it not unfrequently happens that a vein, which contains metallic ore in one part, intermixed with quartz and other vein-ftones, will, in another part, be entirely filled with quartz. Quartz veins interfect almoft all primary and tranfition rocks, but are particularly abundant in rocks of argillaceous fchiftus and greywacke. (See ROCK.) The quartz in veins is moft frequently white, and nearly opaque; and being much harder than the rocks which it interfects, it remains on the fummits of mountains, after the furface of the rock is decompofed, until it is carried down by diluvial currents into the beds of rivers, where it becomes rounded by attrition, and is tranfported to diftant diftricts. Moft of the white quartz pebbles in England have probably been formed from the quartz veins of decompofed rocks, as no quartz of a fimilar kind exifts as a rock in any part of England or Wales; but the fame mineral abounds in veins.

Granite, argillaceous fchift or flate, porphyry, green-ftone, pitch-ftone, bafalt, and various other rocks, frequently form veins in mountains of the fame kind with themfelves, or in different rocks. Where a vein of one kind of rock interfects a rock of a fimilar kind, the fubftance of the vein generally differs from that of the rock in texture, colour, and other characters. The granite in veins, which paffes through granitic rocks, will generally be coarfer or finer grained than the rock which it paffes through, and have the conftituent parts differently mixed. The followers of Werner affert, that veins which contain rock fubftances have been filled from above by matter poured into the fiffures, and that the granite in veins is of a fecondary formation. They further maintain, that the lower rocks, which they confider as the older, never rife into the upper rocks in the form of veins. In oppofition to this opinion, it has been difcovered that veins of granite, in Cornwall, may be diftinctly feen rifing into the fchift or killas which covers the granite rocks in many parts of that county, particularly at St. Michael's mount, eaft of Penzance, and at Moufehole, two miles weft of that town. Where the junction of the granite and fchift is expofed by the action of the fea, veins of the former rock may be traced, at low water, running in a zigzag form for many yards into fchift, gradually growing narrower, and terminating in fmall branches and ftrings. One circumftance we obferved in thefe granite veins at Moufehole, which may deferve notice: the fame vein which penetrated the fchift, when it entered the granite, was different in texture from the granite rock, though it had the fame conftituent parts; it might be diftinctly traced for a confiderable diftance into the granite. The granite alfo, in the vicinity of the fchift, was fmaller grained than the general body of the rock; and the fchift, where in junction with the granite rock or granite veins, was changed to a kind of very fine-grained gneifs. Thefe facts feem to indicate that both the granite and the fchift, to a confiderable diftance from their junction, had been in a foftened ftate at the fame time, and that their confolidation was contemporaneous. Similar appearances, with an intermixture of veins of fchift in granite, are prefented at Glentilt, and other parts of Scotland. Veins of granite, porphyry, or fchift, never penetrate the upper fecondary ftrata; but veins of bafalt and trap (fee TRAP) have been found in every kind of rock, even penetrating chalk. Thefe veins are fometimes of vaft extent and width, and frequently occafion great diflocations and derangements in the ftratified rocks, particularly in the coal ftrata, where they have been moft obferved: hence they are called faults. (See FAULT and STRATA.) The diflocation of the ftrata by a vein of this kind is reprefented in *Plate* II *Geology*, *fig.* 8, where the different ftrata, *c*, *d*, *e*, *f*, *g*, on the left-hand fide, are feparated from the correfponding ftrata on the right, and confiderably elevated.

As the veins of trap or bafalt are nearly vertical, and often feveral yards in width, and the fubftance with which they are filled being frequently harder than the ftrata which they interfect, thefe veins remain when the furface is decompofed to a confiderable depth, rifing like a wall or fence, which, in the language of North Britain, is fynonimous with *dyke*; hence fuch veins have been called *dykes*, or *whin-dykes*, the term whin-ftone being ufed to denote bafaltic rocks. (See WHIN-STONE.) Bafaltic veins, or whin-dykes, vary in width from a few inches to feveral yards, and are fometimes more than one hundred yards wide. They often extend many miles in length; in other inftances they terminate at fhorter diftances, forming irregular wedge-fhaped maffes. When bafaltic dykes are of confiderable

width, the basalt is interſected by fiſſures; and ſometimes the central parts and ſometimes the ſides are harder or ſofter than the other; and in ſome parts the baſalt graduates into a dark ferruginous clay. Maſſes of baſalt from the dyke are frequently found wedged in between the ſtrata, extending to ſome diſtance: and where baſaltic dykes interſect coal ſtrata, the coal in the immediate vicinity of the dyke has frequently the appearance of being charred. At Cork-field-fell, in the county of Durham, the coal ſtrata are cut through by a baſaltic vein or whin-dyke, which is about ſeventeen yards wide. Where it comes in contact with the coal, the latter ſubſtance, for ſeveral feet, is converted into a pulverulent ſtate, like ſoot. At a greater diſtance from the baſalt, the coal is reduced to a coke or cinder, which burns without ſmoke, and with a clear durable heat. At the diſtance of fifty feet from the baſalt, the coal is found in the ſtate of common mineral coal. The roof over the coal is lined with bright cryſtals of ſulphur, probably ſublimed by heat from the pyrites common to coal. In theſe appearances we recognize every circumſtance which might be expected from the agency of heat, but which would be extremely difficult to reconcile with the aqueous formation of baſalt. We have ſeen ſimilar appearances near baſaltic dykes in Northumberland. The vein, or dyke, of baſalt at Cockfield-fell, is part of the longeſt dyke which has been traced in England, or perhaps in any other country. According to the deſcription of it in Mr. Bakewell's Introduction to Geology, "it extends from the weſtern ſide of Durham in an eaſtward direction, to Bewick in Yorkſhire, croſſing the river Tees at this place, and proceeding in the ſame direction through the Cleveland hills, in the Eaſt Riding of Yorkſhire, to the ſea-coaſt between Scarborough and Whitby. It riſes to the ſurface, and is quarried, in many parts of its courſe, for ſtone to repair the roads. It croſſes the turnpike near the ſeven mile-ſtone from Whitby to Pukering, where there is a quarry ſunk in it. The vein, or dyke, is here about ten yards wide; the ſtone is a dark greyiſh-brown baſalt, and is the principal material for mending the roads in the diſtrict called Cleveland. The extent of this dyke has been traced in a direct line about ſeventy miles. In its courſe it interſects the metalliferous lime-ſtone of Durham, the coal diſtrict, and the aluminous ſchiſtus. The circumſtances attending this and other extenſive dykes, which have not hitherto been regarded by geologiſts, completely invalidate," ſays Mr. Bakewell, "the theory, that theſe dykes were originally open fiſſures, formed by the drying or ſhrinking in of the rocks. As the different rock formations through which it paſſes contain different organic remains, they muſt have been formed in ſucceſſion at different periods, and the metalliferous lime, with the lower ſtrata, muſt have been conſolidated long before the upper ſtrata were depoſited; and the cauſes which might diſpoſe the upper ſtrata to ſhrink and open, cannot be ſuppoſed to act on the lower rocks. It is alſo remarkable, that the width of this vein is more than twenty yards in the lower rocks on the weſt; but in the upper rocks it is not more than ten yards. The dyke muſt have been filled with its contents at the time of its formation, otherwiſe it would contain fragments of the rocks which it interſects. As it paſſes through the lime-ſtone, it has rendered it more cryſtalline in its vicinity, and the effects in charring the coal, before deſcribed, point to ſubterranean fire as the original cauſe of its formation, and as the ſource whence the baſalt that fills it was ſupplied. The cloſe reſemblance between the baſalt and compact lava, add probability to the opinion that this great dyke was originally formed by an expanſive force operating from below, which opened a chaſm in the ſurface of the earth, and ejected the contents in a ſtate of fuſion. A volcanic dyke was formed on the weſtern ſide of Veſuvius, June 12, 1794, two thouſand three hundred and ſeventy-five feet in length, and two hundred and thirty-ſeven feet in breadth, through which lava roſe to the ſurface. This lava, when cooled, formed a wall of ſtone interſecting the former beds of lava, and conſtituting a real dyke. The ſtone has a dark-grey colour, and is in ſome parts ſo compact as to reſemble horn-ſtone." See VOLCANO.

The effects of baſaltic veins on the contiguous parts of the ſtrata of ſand-ſtone which they interſect, are no leſs remarkable. In ſome inſtances, the ſand-ſtone appears very conſiderably indurated, and converted into a ſubſtance reſembling horn-ſtone.

It is obſerved by Mr. Allan, Tranſactions of the Royal Society of Edinburgh, vol. vii. that the ſand-ſtone which is thus indurated, contains calcareous earth, which appears to have promoted its ſemi-vitrification; but where the ſand-ſtone remains unchanged in the vicinity of a dyke, the calcareous earth is wanting. Sir G. Mackenzie obſerved baſaltic dykes in Iceland, the walls or ſides of which were lined with a glaſſy ſubſtance reſembling obſidian. Theſe effects offer further illuſtration of the igneous origin of baſaltic veins. A very intereſting account of the effect produced by baſaltic veins on the different beds of rock at the Giants' Cauſeway, and on other parts of the ſame range on the north coaſt of Antrim, is given in the third volume of the Tranſactions of the Geological Society.

Various beds of columnar baſalt, argillaceous lime-ſtone, and chalk, are interſected by perpendicular dykes or veins of baſalt. The chalk in the vicinity often undergoes a remarkable change, extending eight or ten feet from the wall on each ſide, and thence gradually decreaſes. The part neareſt the baſalt is converted into a dark-brown cryſtalline lime-ſtone, like coarſe-grained primitive lime-ſtone. The next ſtate is that of finer-grained primitive lime-ſtone, or ſaccharine lime-ſtone; then fine-grained arenaceous lime-ſtone. A compact variety, having a porcelain aſpect, and a blueiſh-grey colour, next ſucceeds; this, towards the outer edge, becomes gradually white, and inſenſibly graduates into unaltered chalk. The flints in the altered chalk aſſume a greyiſh-yellow colour. The altered chalk is highly phoſphoreſcent when ſubjected to heat. In other parts of the range, the argillaceous beds of lias appear converted into horn-ſtone by contact with the baſalt, and contain in that ſtate the imbedded foſſils peculiar to the lias ſtratum. (See STRATA.) The baſalt in ſome of the veins is columnar; but the columns lie horizontally. It has been conjectured, with ſome probability, that this has been cauſed by its paſſing from a ſtate of igneous fluidity, and the refrigeration commencing from the ſides. From the ſame cauſe, in the beds of columnar baſalt in that range, (ſee GIANTS' *Cauſeway,*) the columns are perpendicular, the cooling commencing from the top and the bottom of each bed. The marine organic remains in the ſtrata over the baſalt, prove that the whole were formed under the ſea. In ſome inſtances, baſaltic veins appear to have been opened, and the intervening ſpace filled with debris from the upper ſtrata; and there are baſaltic dykes in Northumberland, in which the baſalt being divided into irregular maſſes, the interſtices are filled with iron-clay, and contain impreſſions of ferns, like thoſe in the coal ſtrata which theſe dykes or veins interſect. On the whole, no country in the world which has yet been examined preſents ſo many intereſting appearances of baſaltic veins as the northern parts of Great Britain and Ireland, nor are they any where expoſed to the

eye of the obſerver with ſo much diſtinctneſs as on many parts of the ſea-coaſt, where the ocean has bared the ſurface, and expoſed the moſt magnificent and inſtructive ſections of entire mountains, penetrated by theſe veins to the height of many hundred feet. The veins may often be ſeen extending from the mountains into the ſea, riſing up like enormous walls, which ſerve as monuments of the ravages of the ocean upon the coaſt. The great hardneſs of the ſubſtance which fills the veins has prevented their deſtruction by the waves that have broken down and removed the mountain maſſes in which theſe veins were once imbedded.

Meſſrs. Lewis and Clarke, the American travellers, deſcribe extenſive walls of dark columnar ſtone ranging through the interior of North America: theſe walls were undoubtedly dykes or veins of columnar baſalt, remaining where the ſurface of the ground had been waſhed away. There are alſo inſtances where the ſubſtance of baſaltic veins has been ſofter than the ſurrounding rock, and is waſhed out wherever the rock is expoſed, forming deep fiſſures, with perpendicular walls of rocks on each ſide. Such appearances are not uncommon on the ſea-coaſt in various parts of Scotland. For an account of baſaltic rocks, ſee Trap.

Vein is alſo applied to the ſtreaks, or waves, of divers colours appearing on ſeveral ſorts of woods, ſtones, &c. as if they were really painted; and which the painters frequently imitate in painting wainſcots, &c.

Marble is generally full of ſuch veins.

Lapis lazuli has veins like gold. Ovid, ſpeaking of the metamorphoſis of men into ſtones, ſays—"Quæ modo vena fuit, ſub eodem nomine manſit."

Veins, in ſtones, are often a defect, proceeding uſually from an inequality in their conſiſtence, as to hard and ſoft: which makes the ſtone crack, and ſhiver in thoſe parts.

Verdegrease

VERDEGREASE, VERDIGREASE, *Verdegris*, or *Verdigris*, a kind of ruſt of copper, formed from the corroſion of copper by a fermented vegetable, and into a blueiſh-green ſubſtance, of great uſe among painters for a green colour.

The word is formed from the Latin, *viride æris:* it is alſo called *ærugo*. Others call it the *flower*, and others the *vitriolic ſalt of copper;* though, in reality, it is rather the proper ſubſtance of the metal.

The greateſt quantities of verdigris have been manufactured at Montpellier, the wines of Languedoc being very proper for this preparation; and it has been exported thence in cakes, each weighing about twenty-five pounds. The following proceſs for making it is deſcribed by M. Monet, of the Royal Society of Montpellier, and is publiſhed in the Memoirs of the Academy for the years 1750, and 1753. Vine-ſtalks, well dried in the ſun, are ſteeped during eight days in ſtrong wine, and afterwards drained. They are then put into earthen pots, and wine is poured upon them; the pots are carefully covered; the wine undergoes the acetous fermentation, which in ſummer is finiſhed in ſeven or eight days, but requires longer time in winter, although the operation is always performed in cellars. When the fermentation is ſufficiently advanced, which may be known by obſerving the inner ſurface of the lids of the pots, which during the proceſs of the fermentation is continually wetted by the moiſture of the riſing vapours, the ſtalks are then to be taken out of the pots: theſe ſtalks are by this method impregnated with the acid of the wine, and the remaining liquor is but a very weak vinegar. The ſtalks are to be drained during ſome time in baſkets, and layers of them are to be put into earthen pots with plates of Swediſh copper, ſo diſpoſed, that each plate ſhall reſt upon and be covered with layers of ſtalks. The pots are to be covered with lids,

and the copper is thus expofed to the action of the vinegar, during three or four days, or more; in which time the plates become covered with verdigris. The plates are then to be taken out of the pots, and left in the cellar three or four days; at the end of which time they are to be moiftened with water, or with the weak vinegar above-mentioned, and left to dry. When this moiftening and drying of the plates have been thrice repeated, the verdigris will be found to have confiderably increafed in quantity, and it may be then fcraped off for fale.

A folution or erofion of copper, and confequently a verdigris, may be prepared by employing ordinary vinegar inftead of wine, as directed in the above procefs. But it will not have the unctuofity of ordinary verdigris, which is neceffary in painting. Good verdigris muft be prepared by means of a vinous acid or folvent, half acid and half fpirituous. Accordingly, the fuccefs of the operation depends chiefly on the degree of fermentation to which the wine employed has been carried; for this fermentation muft not have been fo far advanced, that no fenfibly vinous or fpirituous part remained in the liquor. Macquer's Dict. Chem. See the procefs as defcribed by Chaptal, under the article Copper.

The Society of Arts, &c. offered a premium in 1756 for the making of verdigris in England; and in 1760 intimated, that it might be made by moiftening with the cheapeft and worft fort of cyder, the marc or remains of apples, pears, goofeberries, currants, floes, crabs, blackberries, or any fruits deprived of their juice by expreffion, proceeding afterwards by the procefs above defcribed. The premiums offered by the Society were feveral times claimed and allowed; and it was refolved, in 1763, that verdigris actually made of Britifh materials, and fubmitted to various trials, was even fuperior to the foreign. Accordingly, a confiderable manufactory was eftablifhed, and fuccefsfully carried on for the purpofe of making verdigris.

The goodnefs of verdigris is judged of from the deepnefs and brightnefs of its colour, its drynefs, and its forming, when rubbed on the hand with a little water or faliva, fmooth pafte, free from grittinefs. This concrete is partially diffoluble in water and rectified fpirit, and almoft totally in vinegar; from the acetous folution, well faturated, and left to exhale flowly in a warm air, the greateft part of the verdigris may be recovered in a cryftalline form, called *diftilled verdigris*. See Crystals *of Venus*, and Copper.

The cryftals, diftilled with a fuitable fire, in a retort or other like veffel, give over the acetous acid in a highly concentrated ftate, but fomewhat altered by the procefs. See Acetic *Acid*.

The matter which diftilled vinegar leaves undiffolved, on being mixed with fome borax and linfeed oil, and fluxed in a crucible, yields a brittle metallic fubftance, of a whitifh colour, not unlike bell-metal. Neum. Chem. by Lewis, p. 64, n. *a*.

Verdigris is employed externally for deterging foul ulcers, and as an efcharotic; but it is feldom ufed, though milder than the fulphate or blue vitriol. It is employed as a collyrium in chronic ophthalmia. Hoffman recommends it particularly for deftroying the callofities of old fiftulæ; tents of powdered verdigris, made up with faliva, or other liquids, not fat or oily, confume, he fays, the hardeft callus in three or four days, fo as to render it completely feparable. A detergent ointment, called *mel ægyptiacum*, is prepared by boiling five parts of verdigris in fine powder with fixteen of honey, and feven of vinegar, till reduced to a clear confiftence. The thinner matter which floats on the top of this mixture, after ftanding for fome time, is generally ufed, unlefs it be required more acid; in which cafe, the thick part which has fubfided is fhook up among it.

In the Edinburgh difpenfatory, an ointment, called *unguentum ex ærugine*, has been directed, compofed of white wax and refin, each two ounces, olive oil one pint, and verdigris half an ounce. When thefe kinds of applications are employed for venereal or other ulcerations in the mouth or tonfils, great caution is neceffary, left they fhould pafs into the ftomach; in which cafe, dangerous and even fatal confequences may enfue.

Verdigris is rarely or never given internally. It has been reckoned tonic, and adminiftered with this view in a dofe under gr. fs. Some recommend it, in the dofe of a grain or two, as an emetic, which produces almoft inftantaneous effect, where poifonous fubftances have been taken, for the immediate rejection of them. But warm water, milk, and oils, are much lefs dangerous, and more proper. In too large dofes, it quickly proves fatal; and, on diffection, the coats of the ftomach appear much thickened, and of a green colour. Lewis's Mat. Med.

M. Navier has lately evinced the falutary effects of liver of fulphur, and particularly of liver of fulphur of Mars, as an antidote againft the poifon of verdigris.

Verdigris makes a blue-green colour in paint; but is generally ufed in yellow, which, by a proper mixture, renders it a true green. It is bright when good; but foon flies, when ufed in oil. When diffolved in vinegar, it is ufed in water painting, and is more durable; it may be alfo diffolved in the juice of rue, and thus produces a fine full green colour, equally fit for wafhing with that diffolved in vinegar.

Verdigris, with a decoction of logwood, ftrikes a deep black, which, when diluted, becomes a fine blue. See Dyeing.

Vernier

VERNIER, is a graduated index which ſubdivides the ſmalleſt diviſions on any ſtraight or circular ſcale, in the reading of which greater accuracy is required, than can be obtained by ſimple eſtimation of a fractional part, as indicated by a pointer, or fiducial edge. The vernier was firſt invented by Pierre Vernier of Franche Comté, and made known to the world at Bruxelles (or Bruſſels) in the year 1631, through the medium of a pamphlet entitled "La Conſtruction, l'Uſage, et les Proprietés du Quadrant nouveau de Mathematique," &c. It ſoon gained the preference over the ſcale of Nonius, which was a circular diagonal ſcale, and which by ſome writers is yet confounded with a Vernier's index, though there is no greater reſemblance between the two, than exiſts between the dial of a clock and the hand that points to it. The vernier is applicable to any ſtraight or circular line, provided the diviſions be equal; but the contrivance of Nonius was in the graduated line or ſcale itſelf, and required the aid of a fiducial edge as an index. We have given the repreſentation of a *vernier* in ſeveral of our aſtronomical plates, when we were deſcribing CIRCLE, EQUATORIAL, QUADRANT, TRANSIT-*Inſtrument*, and THEODOLITE, therefore it will not be neceſſary to introduce any other figure for the purpoſe of illuſtration; particularly as the *principle* of its application can be made clearly intelligible by either arithmetical or algebraical notation. Let us ſuppoſe two lines, either ſtraight or portions of circles, to be exactly alike in dimenſions, one called A, and the other B, and let one of them be divided into more equal parts than the other by *unity*; then will the difference of any two of the equal parts of the two lines, or arcs reſpectively, be a fraction, the numerator of which is the common length of the equal lines, or arcs, and the denominator the product of the numbers of parts into which each is divided. For if we put A for the common length of the equal lines, or arcs, with n and $n + 1$ for the equal parts into which each is divided reſpectively, the length of the diviſions of each will be $\frac{A}{n}$ and $\frac{A}{n+1}$, and their difference $\frac{A}{n} - \frac{A}{n+1}$

$n \times n + 1$

To exemplify this principle in an arc of ſmall radius, let each degree be divided by an engine into three parts, of each 20′, and let it be required that the vernier ſhall read to the accuracy of one minute; in this caſe the ſhort ſcale of the vernier muſt be divided into 20 parts, and the equal arc on the limb of the inſtrument either into 21 or 19 parts, ſo that the difference of the two equal arcs, in diviſions, may be = 1; if 21, the former number, is adopted, the reading will be in a backward direction; but if the latter (*viz.* 19), it will be forward; let the arc on the limb be 6° 20′, and let each degree be divided into three parts, of 20′ each; alſo let 19 be the number of ſuch parts or diviſions; and let the equal arc on the vernier be divided into 20 equal parts; then $n = 19$, and $n + 1 = 20$ will make a difference between a ſingle diviſion of the limb, and one of the vernier $= \frac{6^\circ\ 20'}{19 \times 20} = \frac{380'}{380} = 1'$, as was required. This *difference* becomes the index for ſubdividing the ſmalleſt divided ſpace of the limb, and it is aſcertained how often it muſt be taken, by inſpecting the place on the divided vernier, where a ſtroke on it exactly coincides with a dividing ſtroke on the divided limb of the inſtrument; for inſtance, if the zero, or ſtroke marked 0, be the coincident one, the reading may be had from the diviſions of the limb only, without any addition from the vernier; but if the coincidence happens at any other place, ſay at ſtroke 5, ſtroke 8, or ſtroke 10, as numbered on the vernier, then 5′, or 8′, or 10′, as the caſe may be, muſt be *added*, as the meaſure of a fractional part of a diviſion, to the meaſure read from the diviſions only, that are contained between zero on the limb and zero on the vernier: the difference, which we have ſaid is = 1′ when taken once, is 5′ when taken five times, and 8′ when taken eight times: and as the point of coincidence can never be miſtaken, wherever it may fall, it will always determine how many minutes muſt be *added* for the fractional portion of a diviſion, that zero of the vernier has advanced into an entire diviſion; and as the eye will form a rough judgment at once, whether zero of the vernier is near $\frac{1}{4}$, $\frac{1}{3}$, $\frac{1}{2}$, $\frac{2}{3}$, or $\frac{3}{4}$ of a ſpace on the limb, this notice will at once guide the obſerver to that part of the vernier's ſcale, where the coincidence will be immediately found; for as zero of the vernier advances in any diviſion of the limb, by the ſlow motion of the tangent-ſcrew of any inſtrument, the point of coincidence of the ſtrokes of the two arcs advances with it, till the ſtroke at zero becomes itſelf coincident with a new dividing ſtroke of the arc on the limb, which coincidence denotes the addition of another 20′, in our example, without reference to the vernier: but ſhould there be any doubt about the exactitude of the coincidence, 20″, 30″, or 40″, may be taken inſtead of the laſt minute, accordingly as the eye can beſt judge of

the ſmall quantity ſhort of perfect coincidence; and examining the places of the preceding and following ſtrokes will greatly aſſiſt in forming this judgment.

If we were to ſubſtitute 21 for 19 ſpaces on the limb, the reſult would be the ſame, with the inconvenience of reading backwards, and of ſubtracting inſtead of adding; for $\frac{7^\circ}{21 \times 20} = \frac{420'}{420} = 1'$, as before; but inſtruments of modern conſtruction are exempt from this inconvenience, by having always one more diviſion on the ſcale of the vernier, than on the equal arc of the limb.

In Troughton's ſnuff-box ſextant, which is a very convenient inſtrument for the pocket, the radius of the divided arc is only about $1\frac{3}{4}$ inch, and the degree is divided, therefore, into two ſpaces only, ſo that 30′ are neceſſarily indicated by the vernier; and as 29 ſpaces on the limb are taken equal to 30 on the vernier, the ſmalleſt quantity indicated is $\frac{14^\circ\,30'}{29 \times 30} = \frac{870'}{870} = 1'$, as before; and the reading of the coincidences that indicate the laſt 30′ is progreſſive, like the reading on the limb of the inſtrument.

In the common ebony ſextant, the degree is ſometimes divided into four parts, by reaſon of the increaſed length of the radius; conſequently, when the reading is in a forward direction, fifteen diviſions on the vernier occupy the ſame arc as fourteen on the limb; and the ſmalleſt quantity indicated thereby is $\frac{3^\circ\,30'}{14 \times 15} = \frac{210'}{210} = 1'$; but the braſs ſextants made and divided by the beſt makers, have the minute ſubdivided into twenty, fifteen, ten, or even five ſeconds, according to the length of the radius, by means of a vernier with diviſions and ſubdiviſions, acting with diviſions and ſubdiviſions on the limb, which is a refinement of the original invention, introduced by Troughton, in conſequence of the ſuperior excellence of modern dividing. We have now before us one of Ramſden's beſt braſs ſextants of $9\frac{1}{4}$ inches radius, on the limb of which the degree is divided into three parts, and 40 diviſions on the arc of the vernier meaſure 39 diviſions on the limb; therefore $\frac{13^\circ}{39 \times 40} = \frac{780'}{1560} = \frac{46800''}{1560} = 30''$ is the ſmalleſt quantity that the vernier will indicate, and every alternate ſtroke thereon counts one minute as the coincidence advances. This mode of reading the vernier doubles its former accuracy. But on the limb of this ſame inſtrument, the late Mr. W. Walker prevailed on Mr. Troughton to divide a ſecond arc, within the former, which by our meaſurement is only of nine inches radius: in this inner arc, which reads with the inner arc of the vernier, the degree is firſt divided into halves, and then each half is ſubdivided into five ſmaller diviſions, by ſhorter ſtrokes very delicately cut, ſo that the degree is divided into ten ſmall ſpaces, of 6′ each, which are to be read before the vernier's ſubdiviſion of one of theſe ſpaces is examined. On the ſcale of the inner vernier are 72 ſmall diviſions, co-extenſive with 71 on the limb; and as each of theſe is = 6′, we have $71 \times 6' = 426'$, or 25560″ for the whole arc of meaſurement: conſequently $\frac{25560''}{71 \times 72} = \frac{25560''}{5112} = 5''$ is the ſmalleſt quantity that can be indicated by ſuch a vernier, and accordingly we obſerve on the ſcale of the Vernier twelve ſmall or ſubdividing ſpaces between each minute ſtroke; *i. e.* every twelfth ſtroke is a long one, and they are numbered 1, 2, 3, &c. up to 6, which is the value of one of the ſmalleſt diviſions on the limb, and conſequently the value of each ſubdiviſion on the ſcale is $\frac{1}{12}$ of 1′, or 5″: and yet, by the help of a high magnifier, placed in the centre of an illuminating reflector of plaiſter of Paris, this ſmall quantity may be clearly diſcriminated. When Ramſden firſt ſaw this wonderful application of the powers of the dividing engine, he called his workmen together, to witneſs what he at firſt conſidered the folly of attempting greater accuracy than was practicable; but a cloſe examination of the diviſions convinced him, that his preconceived opinion had ſtood in the way even of his own improvements.

Sometimes a divided head or nut has been fixed on the end of the tangent-ſcrew of ſlow motion, particularly by the older makers of pillar and mural aſtronomical quadrants, in order to ſubdivide the diviſions of the vernier, as may be ſeen at Greenwich, Richmond, and other obſervatories; but when this apparatus has been in uſe ſome time, the parts become looſe and inaccurate, even allowing that the meaſuring ſcrew itſelf can be conſidered as perfect in all reſpects. On an examination of ſome of Graham's, the Siſſons' and Bird's quadrants, we find that though the accuracy of 1″ is profeſſed by the conſtruction, yet very little dependence can be placed on ſuch profeſſion after the parts have been for years in uſe. Of this concluſion Ramſden was no doubt ſenſible, when he introduced into his larger inſtruments the microſcopic readings, with a good ſcrew at the focus of the eye-piece of a compound microſcope, where there is not ſo much ſtreſs on the ſcrew as at the periphery of the arc, where the ſcrew forms alſo a part of the clamping apparatus. To this adoption of the uſe of a compound microſcope, in conjunction with the ſubſequent improvements in the art of dividing, much of the claim to ſuperior excellence in our Engliſh aſtronomical inſtruments is to be attributed, which claim is ſtill further ſupported by the invention of the achromatic object-glaſs and improved eye-pieces of the teleſcopic portion.

Hitherto we have conſidered the principle and application of a ſingle vernier only, which is in itſelf an uſeful and beautiful contrivance; and, as we have ſaid, may be applied with advantage to ſubdivide a ſtraight line; as, for inſtance, the ſcale of a barometer into hundredth parts of an inch, or the ſcale of Dollond's divided object-glaſs micrometer into the five-hundredth parts, or more; but with an entire circle that is graduated all round, the accuracy of an obſervation is greatly augmented, nay enſured, by the uſe of different verniers reading at different parts of the limb at the ſame time. At firſt two diametrically oppoſite verniers were introduced, as has been aſſerted, by one of the Siſſons, though, we underſtand, not with a view to reading at oppoſite ſides of the circle, by way of correcting the obſervation by an average; ſeeing that the remote end of the vernier bar had only a ſingle ſtroke anſwering to zero of the other; but ſubſequently, in tranſit and other inſtruments uſed with a ſpirit-level, the double vernier became a valuable appendage, particularly when the conſtruction of the inſtrument admitted of inverſion of the poſition of the axis, ſo as to procure a double obſervation; and thence the true zero of the graduation of the meaſuring limb. This uſeful property was extended, we believe, by Troughton, firſt by introducing four, and then, with equal advantage, three equidiſtant verniers of ſimilar powers. We have ſhewn the great uſe of additional verniers, at conſiderable length, under our article CIRCLE, particularly with reſpect to the property that three poſſeſs of correcting for the excentricity as well as inequality of the diviſions of a circular inſtrument; and that as great accuracy may be expected from one *croſſed* obſervation with Troughton's reflecting circle, or from a pair of reverſed obſervations with a theodolite, with either circle, that has three verniers, as can be obtained by

a repetition of obſervations on the repeating circle; for, by the mode in which Troughton's circular inſtruments are uſed, the readings will be had at ſix different points of the circle, though very little time is expended in making the obſervations. It is hardly neceſſary to add here, that when an inſtrument is of the reflecting kind, its diviſions are doubly numerous for the ſame radius, when compared with an inſtrument that meaſures only by direct viſion; and that therefore the diviſions on the vernier muſt be calculated to have their dimenſions accordingly. In Troughton's reflecting circle of five inches radius, the degree is divided into three parts, and fifty-nine of theſe are commenſurate with ſixty on the ſcale of each of the three verniers; therefore the exceſs of a ſpace on the limb over one on the vernier is $\frac{1^\circ\ 40'}{60} = \frac{70800''}{3540} = 20''$, which is the ſmalleſt quantity that a ſingle vernier will indicate; but as there are ſix readings in the croſſed obſervation, which obſervation annihilates the errors of zero, and of the darkening glaſſes when uſed, it is to be inferred that the reſult will be accurate to $\frac{20''}{6}$, or little more than *three ſeconds*, if we diſregard the probable errors of reading, and of taking contacts in the obſervation, common to all inſtruments. The figures of the vernier ſcales in this circle count both ways, from each end, becauſe the figures read both to the right and left of zero on the limb, but there can be no miſtake if the figures of the vernier are counted the ſame way that the limb of the circle reads. Formerly the zero of the vernier was placed at the middle of its ſcale; and when it read out at one end, it commenced at the other, and finiſhed again in the middle; but this method, being liable to miſapprehenſion, is now diſcontinued.

In an eighteen-inch aſtronomical circle, by Troughton, at preſent under our examination, which has four verniers at equal diſtances, and turns in azimuth, the degree is divided by Engine into twelve diviſions, of which 59 fill the ſame arc as 60 on the verniers reſpectively; hence we have $59 \times 5' = 295'$, or $17700''$ for the numerator, and $59 \times 60 = 3540$ for the denominator, and $\frac{17700''}{3540} = 5''$, the ſmalleſt quantity that one vernier will indicate; and accordingly the ſpace between zero and $1'$ on the vernier is ſubdivided in 12 ſmaller ſpaces, ſo that each ſucceſſive coincidence will mark out $5''$ on each ſeparate vernier; but as there are four verniers, and as the circle will reverſe in poſition by means of the azimuthal motion, there will be virtually eight readings from which to take an average of $5''$, ſo that the probable accuracy reſulting from ſuch average comes *within the ſecond*, and would have done ſo if there had been only three verniers. Hence the advantage gained over the average of the verniers by microſcopic readings, is probably not ſo great as is generally ſuppoſed.

Vinegar

VINEGAR, Acetum, an agreeable, acid, penetrating liquor, prepared from wine, cyder, beer, and other liquors, and varying in hue from light red to brown ſtraw-colour, malt vinegar being more highly coloured than that of wine: and of conſiderable uſe, both as a medicine and a ſauce: or, vinegar is a vegetable acid liquor, produced by the ſecond degree of fermentation, or that which ſucceeds the ſpirituous, and is called the acid or acetous fermentation. Every liquor, which has completely undergone the ſpirituous fermentation, is ſpontaneouſly and neceſſarily diſpoſed to the acid fermentation. Accordingly, every vinous liquor does continually tend to become vinegar, and is actually changed into it, ſooner or later, according to circumſtances; unleſs this change be prevented by ſome obſtacle to fermentation in general. If vinegar be long kept, and particularly if it be expoſed to the air, it will become muddy and ropy, acquiring an unpleaſant ſmell, loſing its acidity, and putrefying. In order to preſerve it for a longer time, it ſhould be boiled for a few minutes, ſo that the gluten may coagulate and ſeparate, on the preſence of which theſe changes depend, and alſo kept in well-corked bottles.

The word is French, *vinaigre;* formed from *vin*, *wine*, and *aigre*, *ſour*.

The method of making vinegar has long been kept a ſecret among the people of that profeſſion; who, it is ſaid, oblige themſelves to each other by oath not to reveal it; but, notwithſtanding this, the Philoſophical Tranſactions, and ſome other late writings, furniſh us with approved accounts of it. Whatever be the materials uſed in the preparation of the liquor for producing vinegar, it is merely neceſſary to admit air into the veſſel in which it is kept, and to preſerve it in a temperature ſomewhat higher than that of the atmoſphere in this climate, that is, from about 75° to 80°. When a liquor already fermented is uſed, it is alſo of almoſt indiſpenſable importance that yeaſt, or ſome other ferment, be added, in order to haſten the fermentation, or elſe the change will be too gradual to obtain vinegar in perfection, and the firſt acetified portion will turn mouldy before the laſt has become ſour. But if the material employed has not undergone fermentation, the whole proceſs of the vinous and preceding acetous fermentation will go on without interruption, with the ſame ferment which firſt ſet it in action, as, *e. g.* in making vinegar from malt, or from ſugar and water. It is neceſſary alſo to ſtop the proceſs of the manufacture in that ſtage of it, in which the acid has attained to its higheſt degree of ſtrength and perfection, after which the liquor would then ſpeedily be deteriorated, the acetous acid would gradually diſappear, and an offenſive mouldy watery liquor remain, with ſcarcely any acidity. It depends upon the ſkill and experience of the manufacturer to determine when his vinegar is in a fit ſtate to be drawn off and cloſely barrelled.

Vinegar, *Method of making Cyder.* The cyder (the meaneſt of which will ſerve the purpoſe) is firſt to be drawn off fine into another veſſel, and a quantity of the muſt, or pouze of apples, to be added; the whole is then to be ſet in the ſun, if there be a conveniency for the purpoſe; and, at a week or nine days end, it may be drawn off.

Vinegar, *Method of making Beer.* Take a middling ſort of beer, indifferently well hopped; into which, when it has worked well, and is grown fine, put ſome rape, or huſks of grapes, uſually brought home for that purpoſe; maſh them together in a tub; then, letting the rape ſettle, draw off the liquid part, put it into a caſk, and ſet it in the ſun as hot as may be; the bung-hole being only covered with a tile, or ſlate-ſtone; and in about thirty or forty days it will become a good vinegar, and may paſs in uſe as well as that made of wine, if it be refined, and kept from turning muſty.

Or, vinegar may be made thus: To every gallon of ſpring-water, add three pounds of Malaga raiſins; which put into an earthen jar, and place them where they may have the hotteſt ſun from May till Michaelmas; then preſſing all well, tun the liquor up in a very ſtrong iron-hooped veſſel, to prevent its burſting: it will appear very thick and muddy, when newly preſſed; but it will refine in the veſſel, and be as clear as wine. Thus let it remain untouched for three months, before it be drawn off, and it will prove excellent vinegar.

Vinegar, *To make Wine.* Any ſort of vinous liquor, being mixed with its own fæces, flowers, or ferment, and its tartar firſt reduced to powder; or elſe with the acid and auſtere ſtalks of the vegetable from whence the wine was obtained, which hold a large proportion of tartar: and the whole being kept frequently ſtirring in a veſſel which has formerly held vinegar, or ſet in a warm place full of the ſteams of the ſame, will begin to ferment anew, and conceive heat, and will grow ſour by degrees, and ſoon after turn into vinegar.

The remote ſubjects of acetous fermentation are the ſame with thoſe of vinous; but the immediate ſubjects of it are all kinds of vegetable juices, after they have once undergone that fermentation which reduces them to wine; for it is abſolutely impoſſible to make vinegar of muſt, the crude juice of grapes, or other ripe fruits, without the previous aſſiſtance of vinous fermentation.

The proper ferments for this operation, by which vinegar is prepared, are, 1. The fæces of all acid wines. 2. The lees of vinegar. 3. Pulverized tartar; eſpecially that of Rheniſh wine, or the cream or cryſtals of it. 4. Vinegar itſelf. 5. A wooden veſſel well drenched with vinegar, or one that has long been employed to contain it. 6. Wine that has often been mixed with its own fæces. 7. The twigs of vines, and the ſtalks of grapes, currants, cherries, or other vegetables of an acid auſtere taſte. 8. Bakers' leaven, after it is turned acid. 9. All manner of ferments, compounded of thoſe already mentioned.

Vinegar is no production of nature, but a mere creature of art: for verjuice, the juices of citrons, lemons, and the like native acids, are improperly ſaid to be *natural* vinegars; becauſe, when diſtilled, they afford nothing but vapid water; whereas it is the property of vinegar to yield an acid ſpirit by diſtillation.

The wine which is generally converted into vinegar, and which for its cheapness is commonly employed for this purpose, is such as has already become sour; although the better and the more spirituous the wine, and also the more of the vinous spirit that can be retained in the vinegar, the better and stronger it will be. Becher says, in his "Physica Subterranea," that having digested wine in order to convert it into vinegar, in a bottle hermetically sealed, he found, that although a longer than the ordinary time was required, the vinegar produced was much stronger than when free air is admitted. Mr. Cartheuser also affirms, that the strength of vinegar may be much increased by adding some aqua vitæ to the wine, before it is exposed to the acetous fermentation. Nothing more seems requisite in the preparation of good vinegar than to employ good wine, and to conduct the fermentation in the most advantageous method; the principal part of the operation being performed by nature.

VINEGAR *in France, Method of making.* The French use a method of making vinegar different from that above described. They take two very large oaken vessels, the larger the better, open at the top; in each of which they place a wooden grate, within a foot of the bottom: upon these grates they first lay twigs, or cuttings of vines, and afterwards the stalks of the clusters of grapes, without the grapes themselves, or their stones, called the *rape*, till the whole pile reaches within a foot of the brim of the vessels; then they fill one of these vessels with wine to the very top, and half fill the other; and with liquor drawn out of the full vessel, they fill up that which was only half full before; daily repeating the same operation, and pouring the liquor back from one vessel to the other; so that each of them is full and half full by turns.

When this process has been continued for two or three days, a degree of heat will arise in the vessel which is then but half full, and will increase for several days successively, without any appearance of the like in the vessel which happens to be full during those days; the liquor of which will still remain cool: and as soon as the heat ceases in the vessel that is half full, the vinegar is prepared; which, in the summer, happens on the fourteenth or fifteenth day from the beginning; but, in the winter, the fermentation proceeds much slower; so that they are often obliged to forward it by artificial warmth, or the use of stoves.

When the weather is exceedingly hot, the liquor ought to be poured off from the full vessel into the other twice a day; otherwise the liquor would be over-heated, and the fermentation would prove too strong; whence the spirituous parts would fly away, and leave a vapid wine, instead of vinegar, behind.

The full vessel is always to be left open at top; but the mouth of the other must be closed with a cover of wood, in order the better to keep down and fix the spirit in the body of the liquor; for, otherwise, it might easily fly off in the heat of fermentation. The vessel that is only half full seems to grow hot, rather than the other, because it contains a much greater quantity of the vine-twigs and stalks than that, in proportion to the liquor; above which the pile rising to a considerable height, conceives heat the more, and so conveys it to the wine below. Boerhaave's Elem. of Chemistry, part iii. p. 143, &c. Phil. Trans. vol. ii. p. 657.

There is another method, by which a very good vinegar is commonly made at Paris from the lees of wine. A quantity of wine-lees is put into a large tun, and worked up with wine sufficient to render it very fluid. This is then put into cloth sacks, which are arranged in a large iron-bound wooden vat, the heavy cover of which is laid over them, and serves as a press, that is gradually screwed down till all the liquor is pressed out. The wine, thus loaded with the extractive and tartareous matter of the lees, is distributed in large casks set upright, through the heading of which a hole is cut, which is constantly left open. In summer these casks are simply set in the sun; but in winter they are arranged in a stoved room. The fermentation comes on in a day or two, and when it has got to its height, so much heat is excited, that sometimes the hand can hardly be borne in it. In this case, it must be checked by a cooler air, and by adding some fresh wine to the casks; and, indeed, it is in a due regulation of the heat that most of the practical skill of the maker consists. The process goes on in this way till the whole of the wine is thoroughly acidified, which requires about a fortnight in summer and a month in winter; after which the new vinegar is put into barrels, at the bottom of which are laid a good many chips of beech wood. Here it remains for about a fortnight, during which time it clarifies, and the clear part is then drawn off and kept in well-closed casks. These beech chips may be used over and over again for several years.

The natural colour of good wine-vinegar is a very pale red, but a higher colour is given, if desired, by the addition of elder-berries.

There are several slight variations in the mode of making wine-vinegar, but which need not be detailed. They all consist in exciting a fresh fermentation in wine, and keeping it up in a moderate degree till acetification is complete. Many refuse parts of the vine are of use for this purpose, such as the husks, the sour succulent twigs, the marc or cake left in the wine-press, and the like; and after they have once served, they are still more valuable, as the acid which they naturally contain, or which is evolved by them, is more readily produced.

Wine may also be converted to good vinegar without these additions, simply by adding wine, especially when on the fret, to vinegar already made, and exposing it to a proper heat. In this way many manufacturers proceed, keeping their casks always full, by taking out of them at intervals about a third or fourth part, replenishing them with wine, and again bringing the contents to the state of vinegar.

In this country vinegar is chiefly made from malt. The following is the usual process in London. A mash of malt and hot water is made, which, after infusion for an hour and a half, is conveyed into a cooler a few inches deep, and thence, when sufficiently cooled, into large and deep fermenting tuns, where it is mixed with yeast, and kept in fermentation for four or five days. The liquor (which is now a strong ale without hops) is then distributed into smaller barrels, set close together in a stoved chamber, and a moderate heat is kept up for about six weeks, during which the fermentation goes on equally and uniformly till the whole is soured. This is then emptied into common barrels, which are set in rows (often of many hundreds) in a field in the open air, the bung-hole being just covered with a tile to keep off the wet, but to allow a free admission of air. Here the liquor remains for four or five months, according to the heat of the weather, a gentle fermentation being kept up, till it becomes perfect vinegar. This is finished in the following way. Large tuns are employed, with a false bottom, on which is put a quantity of the refuse of raisins or other fruit left by the makers of raisin and other home-made wines, called technically *rape.* These rape-tuns are worked by pairs; one of them is quite filled with the vinegar from the barrels, and the other only three-quarters full, so that the

fermentation is excited more eaſily in the latter than the former, and every day a portion of the vinegar is laded from one to the other, till the whole is completely finiſhed and fit for ſale.

Vinegar, as well as fruit-wines, is often made in ſmall quantity for domeſtic uſes, and the proceſs is by no means difficult. The materials may be either brown ſugar and water alone, or ſugar with raiſins, currants, and eſpecially ripe gooſeberries. Theſe ſhould be mixed in the proportions which would give a ſtrong wine, put into a ſmall barrel, which it ſhould fill about three-fourths, and the bung-hole very looſely ſtopped. Some yeaſt, or, what is better, a toaſt ſopped in yeaſt, ſhould be put in, and the barrel ſet in the ſun in ſummer, or a little way from a fire in winter, and the fermentation will ſoon begin. This ſhould be kept up conſtant, but very moderate, till the taſte and ſmell indicate that the vinegar is complete. It ſhould be poured off clear and bottled carefully, and it will keep much better if it is boiled for a minute, cooled and ſtrained before bottling.

In both the vinous and acetous fermentations, an inteſtine motion, a ſwelling, a hiſſing noiſe, and an ebullition, may be perceived; but the heat produced by the former is ſcarcely ſenſible, whereas that produced by the latter is very conſiderable. Moreover, the vapour which exhales from vinegar, during fermentation, is not noxious, like that of fermenting wine: on the contrary, as the acid of vinegar diſengages itſelf, it ſeems to acquire more power to bind and retain the inflammable principle, which is the truly dangerous part of theſe vapours. Beſides, vinegar does not depoſit tartar as wine does, even though it has been made with wine that had not depoſited its tartar; but the ſediment of vinegar is a viſcid, oily, and very putreſcent matter; which is uſed to cover the grape-ſtalks that are employed in the making of vinegar, in order to promote the fermentation. The acid of the grape-ſtalks, which are waſhed clean and preſerved to promote the fermentation of more vinegar, acts powerfully as a leaven or ferment. The caſks which have been uſed are alſo to be cleanſed from the viſcid matter juſt mentioned, and kept for the ſame uſe, as they are fitter for the purpoſe than new caſks. When the acetous fermentation is finiſhed, the nature and character of the liquor that has undergone it are totally changed. The taſte and ſmell of wine are partly ſpirituous and partly acid; though in good wine the latter is ſcarcely perceptible: the taſte and ſmell of vinegar are alſo acid and ſpirituous; but the former quality prevails ſo much, as almoſt totally to conceal the latter. The properties of wine and vinegar prove, that the acetous fermentation unfolds in a very ſingular manner the acid parts of wine, and intimately combines them with the inflammable ſpirit; ſo that by changing wine into vinegar, the ardent ſpirit is no longer perceptible, ſo that it cannot affect the head and intoxicate; and if it be diſtilled, the firſt liquor that riſes with a heat leſs than that of boiling water is not an ardent ſpirit, as when wine is diſtilled, unleſs the vinegar be too new, and the acetous fermentation has not been completely finiſhed; but when old vinegar is diſtilled, the liquor that firſt riſes is a ſlightly acid phlegm, which contains the moſt volatile, the moſt odoriferous, and the moſt ſpirituous part of the vinegar.

When vinegar has run a little beyond the acetous ſtate, and begun to enter on the putrefactive, the putrefaction may be ſtopped by quenching a red-hot iron in the liquor; and the acid, which has been loſt, may in ſome meaſure be reſtored, by the addition of a little ſpirit of wine, rye-bread, muſtard-ſeed, &c. The putrefaction of vinegar may alſo be prevented, by racking it off from the feculencies, and keeping it in a cloſe-ſtopped veſſel, in a cool place. However, ſuch as has once ſuffered a conſiderable heat, cannot long be preſerved from corruption.

In England, the exciſe laws relating to vinegar are as follow:

Every maker of vinegar for ſale ſhall take out a licence, for which he ſhall pay 10*l.*; and ſhall renew the ſame annually ten days at leaſt before the end of the year; on pain of 50*l.* 43 Geo. III. c. 69. Sched. (A.) 24 Geo. III. c. 41.

But perſons in partnerſhip need only take out one licence for one houſe.

By 43 Geo. III. c. 68. for all vinegar or verjuice imported, a certain duty ſhall be paid *per* ton (quantity 252 gallons).

By 43 Geo. III. c. 69. Sched. (A.) for every barrel of vinegar, vinegar beer, or liquors preparing for vinegar, which ſhall be brewed or made in Great Britain for ſale, ſhall be paid by the maker a certain other duty.

And upon every hogſhead of verjuice which ſhall be made in Great Britain for ſale, ſhall be paid by the maker a certain duty.

And by 49 Geo. III. c. 98. a duty is impoſed in lieu of all former duties of cuſtoms.

By 10 & 11 W. c. 21. thirty-four quarts ſhall be accounted a gallon of vinegar, according to the ſtandard ale quart.

Every vinegar-maker ſhall make entry with the officer of exciſe of the houſe or place where he intends to carry on the buſineſs; and whether he intends to make vinegar from malt or corn, or molaſſes or ſugar, or from any and what other materials. 26 Geo. III. c. 73.

Such officer may at all times by day and night (but if in the night, in the preſence of a conſtable), enter into any places uſed by ſuch perſons, and take an account of ſuch liquors therein, and ſhall make a report thereof in writing to the commiſſioners, leaving a true copy thereof under his hand, with ſuch maker, if demanded, in writing, under the penalty of 10*l.* 7 & 8 W. c. 30. 12 Geo. c. 28. 12 Ch. c. 24.

By 10 & 11 W. c. 21. no vinegar-maker ſhall receive into his cuſtody any liquors for making vinegar, nor deliver out any vinegar in caſks, or by the gallon, without notice firſt given to the officer, unleſs from Sept. 29, to Mar. 25, yearly, between ſeven in the morning and five in the evening, and from Mar. 25, to Sept. 29, between five in the morning and ſeven in the evening; on pain of 50*l.*

On receiving ſuch liquors into his cuſtody, he ſhall ſhew the ſame to the gauger before he mixes them with any other liquors, rape, or other materials; on pain of 20*l.*

If any vinegar-maker ſhall, without giving notice at the next exciſe-office, or to one of the commiſſioners, uſe any ſtore-houſe, warehouſe, cellar, or other place, for making or keeping any vinegar beer, or liquor preparing for vinegar, he ſhall forfeit 50*l.*

If any maker of vinegar for ſale ſhall conceal any vinegar, or liquor preparing for vinegar, from the view of the gauger, he ſhall for every barrel forfeit 40*s.* 7 & 8 W. c. 30.

If ſuch maker ſhall, on demand made by ſuch gauger in the day-time (or if by night, in the preſence of a conſtable), refuſe to permit him to enter his houſe, ſtore-houſe, or other place uſed by him, and to take an account of the ſaid liquors, he ſhall forfeit 15*l.*

No perſon carrying on the trade of a vinegar-maker from molaſſes or ſugar, or other materials, (except malt or corn,) ſhall carry on (either alone or in partnerſhip) the trade of a

distiller or rectifier of spirits in the same premises, or within two miles thereof; and all entries made by such person shall be void. 26 Geo. III. c. 73.

All stale beer, returns of beer or ale, cyder, verjuice, or any other liquor proper to be made into vinegar, which shall be found in the possession of any common vinegar-maker, except such as are to be drunk in his family, and which shall be kept separate for that purpose, shall be deemed vinegar or liquors preparing for vinegar. 10 & 11 W. c. 21.

Every such vinegar-maker shall make entry once a month at the next excise-office of all liquors made within that month, and also within a month after such entry, shall clear off the duties, on pain of double duty. 12 Ch. II. c. 24.

All penalties and forfeitures are to be recovered, levied, and mitigated as by the excise laws. 43 Geo. III. c. 69.

Vinegar, *Chemical Properties of the pure Acid of the different Kinds of.* See Acetous *Acid.*

The quantity of fixt alkaline salt which vinegar is capable of saturating, is one of the surest criterions of its strength. The best of the German vinegars, according to Stahl, saturate little more than $\frac{1}{40}$th of their own weight; the French vinegars, examined by Geoffroy, above $\frac{1}{13}$th; and some of them no less than $\frac{1}{12}$th; the common distilled vinegar of our shops about $\frac{1}{20}$th. By congelation, and distillation from alkalies, and from some metallic bodies, particularly copper, the acid may be so far concentrated as to saturate nearly equal its own weight. The best way of judging of the saturation, according to Dr. Lewis, is by trying the liquor from time to time with certain coloured vegetable juices, or on paper stained with them. For this purpose, a thick writing paper may be stained pale blue on one side with the blue preparation of archil, commonly called lacmus; and pale red on the other side, by a mixture of the same infusion with so much diluted spirit of salt as is just sufficient to redden it. If a small slip of this paper be dipped occasionally into the liquor to be tried, or a drop of the liquor be applied on both sides of the paper, the red side turns blue as long as any of the alkali remains unsaturated; the blue side turns red, when the acid begins to prevail; and no change at all is produced, when the saturation is complete. Where lacmus cannot be procured, the paper may be coloured with the juices of violets, iris, cyanus, &c. or with the blue juice pressed out from scrapings of the cortical part of common radish roots; with which it is sufficient to stain the paper on one side; this one colour discovering both acidity and alkalescence, the former changing it red, and the latter green.

The acetous acid differs essentially from all the others: from the native vegetable acid, in subtility and volatility; not being obtainable in the form of a concrete salt, which most, perhaps all, of the native ones are, and rising in distillation with a moderate heat, which very few of the native ones have been found to do: from the mineral acids, in its habitude to different bodies, and the nature of the compounds which it forms with them, being much weaker than the mineral acids: thus, whatever alkaline, earthy, or metallic substance the acetous acid be combined with, the addition of any mineral acid will disjoin them, the mineral taking the place of the acetous; neutral salts, composed of the acetous acid and fixed alkalies, dissolve totally and plentifully in rectified spirit of wine, whilst those composed of the same alkalies and mineral acids are not at all soluble in that menstruum: in this property, the acetous acid differs also from most, perhaps from all, of the acids of its own kingdom; and from all acids in general, in its peculiar odour.

The acid of vinegar dissolves all substances upon which other acids can act, and forms with them neutral salts, all which may be called acetous salts. With calcareous earth it forms salts, which in crystallizing shoot into silky ramifications and vegetations: these salts are named, from their earthy bases, salt of chalk, salt of crabs' eyes, &c. (See Acetite *of Lime*, &c.) The solubility of calcareous earth in this acid, and its precipitability by that of vitriol, afford a ready method of discovering the sophistication of vinegar, said to be sometimes practised, with vitriolic acid. If a saturated solution of any calcareous earth, as chalk, made in strong vinegar, be added to such as is suspected of containing vitriolic acid, no change will ensue, if the vinegar was pure; but if it contained even a minute portion of that acid, the mixture will immediately become milky, and, on standing for a little while, deposit a milky sediment: if the calcareous solution be gradually dropt in, so long as it produces any milkiness or cloudiness, all the vitriolic acid will be absorbed by the chalk; and as this new compound is very sparingly dissoluble, nearly the whole of it will precipitate, so as to leave the vinegar almost pure. Its adulteration with vitriolic or sulphuric acid may also be detected by a solution of nitrate of barytes, which forms a white precipitate, when dropped into the suspected vinegar, insoluble in nitric acid, after having been exposed to a strong heat. With fixed vegetable alkali the acid of vinegar forms a very pungent and very deliquescent salt, called *Regenerated* Tartar, or Terra *foliata tartari*; which see. (See also Acetite *of Potash.*) With fixed mineral alkali it forms a neutral crystallizable salt. With volatile alkali it forms an acetous ammoniacal salt, called *spirit of Mindererus*. See Acetite *of Ammonia.*

Vinegar dissolves, among metallic bodies, zinc and iron; and the rest with difficulty, if at all. (See Acetous *Acid.*) United with copper, it forms a verdigris and crystals of Venus. With lead it forms ceruse, and salt or sugar of lead; dissolving it more easily when reduced to a calx than in its metallic state; boiled even with the glass of lead, or in the common glazed earthen vessels, in the glazing of which this metal is a principal ingredient, it extracts so much as to become strongly tainted with the pernicious qualities of the lead. Gold, platina, silver, and quicksilver, are not affected by vinegar in their metallic state; the two first have not been observed in any state to be affected by it. Silver precipitated from the nitrous acid, and thoroughly edulcorated with water, and mercury treated in the same manner, or changed by fire into a red powder, slowly and sparingly dissolve in it. Of the affinities of this acid to different metals, or its forsaking one to unite with another, few experiments have been made. Dr. Lewis observes, that it deposits lead and copper upon adding iron. (See *Tables of* Affinity.) It dissolves the vegetable inspissated juices, and several of the gummy resins, and extracts the virtues of sundry plants in tolerable perfection, superadding at the same time a virtue of a different kind. However, it excellently assists and coincides with some drugs, as garlic, squills, and ammoniacum; and in many cases, where this acid is principally to be depended upon, it may be advantageously impregnated with the flavour of certain vegetables. Vinegar very much concentrated, as the rectified spirit of Venus, or radical vinegar, being distilled with equal parts of highly rectified spirit of wine, furnishes a liquor which has all the essential characters of ether, and is called *acetous ether*. It was discovered by the count de Lauraguais. (See Hist. Acad. Scienc. Par. 1759.) It mingles equally with blood and its serum, and with most of the fluids of animals; not thickening or coagulating them, like the acids

of the mineral kingdom, but tending rather, as Boerhaave justly observes, to attenuate and resolve coagulations. It is likewise, when taken internally, less stimulating than the mineral acids, and less disposed to affect the kidneys. Professor Cullen observes, that it is less liable to undergo changes in the first passages than the native vegetable acids, which have yet to go through the process of fermentation. The use of vinegar as a condiment, and as an antiseptic for pickling and preserving dead animal and vegetable matter, is well known.

Vinegar, *Medicinal Properties of.* This mild, unctuous acid is a medicine of great use in the different kinds of inflammatory and putrid distempers, both internal and external. Nothing is more extolled in many cases of putrefaction, and as an antidote against venomous bites, by Dioscorides and Hippocrates, than oxycrate; and vinegar, when applied to sores in animal bodies, is known to stimulate and resist putrefaction. When weak, it possesses the virtues of water; when strong, its effects approach to those of salts and acid spirit. Med. Eff. Edinb. vol. v. art. 24.

It is one of the most certain antiphlogistics and sudorifics in high fevers, and one of the best preservatives against pestilential and other putredinous contagions. Accordingly Boerhaave informs us, that Franciscus de la Boe Sylvius visited his patients in the plague with safety, by drinking first an ounce or two of vinegar. And it is now a common practice to wash and sprinkle the rooms of hospitals, the decks of ships, &c. with vinegar, in order to purify the air. Dr. Hales (Ventilators, part i. p. 46.) recommends dipping many cloths in vinegar, and hanging them up in all proper vacancies between the decks of ships, and in the chambers of sick persons, by which great quantities of vinegar would intermix and float in the air; and he found by an experiment, mentioned in his Statical Essays, vol. i. p. 266, that an air which passes through such cloths, could be breathed to and fro as long again, as the like quantity of air which was not impregnated with vinegar. Fainting, vomiting, lethargic and hysteric paroxysms, are likewise frequently relieved by vinegar, applied to the mouth and nose, or received into the stomach. Lethargic persons are often found to be excited more effectually by vinegar blown into the nose, than by the far more pungent volatile spirits. Boerhaave observes, that this acid counteracts, in a peculiar manner, the effects of spirituous liquors. The daily use of vinegar with food is salutary in hot, bilious dispositions, and where there is a tendency to inflammation or putrefaction. It is prejudicial to children, to aged, hysterical, and hypochondriacal persons; in cold, pale, phlegmatic habits, where the vessels are lax, the circulation languid, and the power of digestion weak. It tends in all cases, if used freely, to prevent corpulence. Hoffman suspects that it produces this effect by impeding the formation of chyle, or destroying the union of the unctuous and serous fluids of which chyle is composed; an effect common to all acids, as appears from their coagulating milk and artificial emulsions. Dr. Lewis observes, that he has known great corpulence reduced by the liberal use of vinegar, but not with impunity: diseases succeeding, which eluded the power of medicines, and proved at length fatal.

Combinations of vinegar with different earthy bodies, differ in virtue according to the nature of the earth. A solution of the aluminous earth in this acid is strongly styptic; of vegetable earth, or magnesia alba, bitterish and gently purgative: both these solutions are milder, and less ungrateful, than those of the same earths made in the mineral acids; and, though as yet unknown in practice, certainly deserves, as Dr. Lewis says, to be introduced. Solutions of different animal and the calcareous mineral earths are bitterish and subaustere, in various degrees, and supposed to act as mild resolvents, subastringents, or diaphoretics. Combinations of vinegar with fixed alkaline salts are useful aperients, diuretics, and cathartics. Dr. Lewis has known two drachms of the alkali, dissolved in as much vinegar as was sufficient to saturate it, occasion ten or twelve copious watery stools, and a plentiful discharge of urine, without griping or fatiguing the patient. Mixtures of alkali and distilled vinegar, evaporated to a dry salt, are kept in the shops; either in a brownish oily state, as obtained by simple evaporation, or purified to perfect whiteness, by gentle fusion or solution in water. These preparations are given in doses of ten or twenty grains as mild aperients, and to a drachm or two as purgatives and diuretics. See Tartar, *Regenerated*, Sal *Diureticus*, Terra *Foliata*, and Arcanum *Tartari*.

Combinations of vinegar with volatile alkaline salts, commonly made with distilled vinegar, added gradually to the salt, till the effervescence ceases, scarcely yield any solid salt; the saline matter evaporating with the watery fluid, or even before it: on distilling the mixture in a retort, a salt sometimes concretes about the sides of the receiver, but liquefies again as the vessels grow cold. These mixtures, called *spiritus Mindereri*, have little purgative virtue, but operate powerfully as aperients; by urine, if the patient walks about in the cool air; by perspiration or sweat, if kept warm in bed. They are principally made use of in this last intention, in doses of half an ounce; and, as they act without irritation, they have place in inflammatory cases, where the warm sudorifics, if they fail of exciting a sweat, aggravate the distemper. Vinegar and honey, or oxymel, of the consistence of a syrup, swallowed warm, is very good in many cases of sore throats arising from colds. A very important medicinal virtue has been attributed to vinegar, namely, that of curing the canine madness. See Hydrophobia, and Madness *from the Bite of enraged Animals*.

M. Buchoz, in a work, entitled "An historical Treatise of Plants growing in Lorraine, &c." affirms, that several successful trials have ascertained the efficacy of vinegar against the ill effects arising from the bite of mad dogs, when it is given in the quantity of a pound each day, divided into three doses; one to be taken in the morning, another at noon, and a third in the evening. Upon the whole we shall here observe, that vinegar, taken into the stomach, acts as a refrigerant, promotes diaphoresis and the discharge of urine; and is a powerful antinarcotic: externally its action on the living fibre is moderately stimulant and astringent. In inflammatory fevers it may be used to acidulate the ordinary beverage. It is given as a remedy in putrid diseases and scurvy; and is the most easily procured, and the best means of counteracting the fatal effects of overdoses of opium, and other narcotic poisons; for which purpose it should be administered in table spoonfuls, frequently repeated, after the stomach has been emptied by a proper emetic. It is employed as a glyster in obstinate costiveness; and externally, in the form of fomentation, or of lotion, is applied in burns, bruises, sprains, and chronic ophthalmia; and diluted with water, it is the best lotion for clearing the eye of small particles of lime, when they adhere to any part of the ball, or the lids. Its vapour is inhaled in putrid sore-throat; and diffused through sick rooms, with the view of neutralizing pestilential effluvia; but as a fumigation it has little efficacy. The dose of vinegar is f℥j to f℥ij; and the quantity given in clysters f℥j to f℥ij. See on the subject of this article, Boerhaave's Elem. Chem. by Dallowe, part iii. p. 146, &c. Neumann's Chem. by Lewis, p. 458, &c.

Dict. Chem. Lewis's Mat. Med. Thomfon's Lond. Difp. See alfo ACETIC *Acid*, ACETITE, ACETOUS *Acid*, and ACETUM.

VINEGAR, in *Rural Economy*, is an acid or cooling liquid that may be made ufe of with confiderable benefit in different forts of field labour, in mixture with water or other fluids, as quenching thirft very effectually, without ftimulating or increafing the heat of the body too greatly. It has been ftated, on the authority of a manufcript paper found in poffeffion of fir William Pulteney on the ufe of vinegar, by the writer of the Corrected Report of the Agriculture of the County of Middlefex, that during the firft American war, the interruption given by our cruizers to the trade of that country, and fome other circumftances, prevented the inhabitants of it from procuring proper fupplies of molaffes for their diftilleries, and a diftrefs was experienced, particularly in harveft-time, from the want of rum to mix with water, which was the drink of their labourers. It is commonly known, the writer thinks, that cold water is dangerous, when ufed by perfons heated with labour, or by any fevere exercife; and yet it is neceffary to fupply the wafte and exhauftion of perfpiration in fome mode or other. When rum or wine is added in fmall quantity to water, it may be ufed, even if cold, with little danger: it would, however, be fafer, it is fuppofed, if a little warm water were mixed and employed in fuch cafes.

On this account, Dr. Rufh, of the fame country, after making proper experiments on the fubject, recommended in a publication, that inftead of rum, which could not then be had, the labourers in harveft fhould mix a very fmall proportion of vinegar with the water they made ufe of as drink. Some years afterwards, in another publication, the fame writer mentioned that the practice had been adopted, and had fucceeded even beyond his expectations; indeed fo much fo, that in many places vinegar was ftill continued to be ufed, though rum could eafily be had. The preference of vinegar to rum is accounted for in this manner: fevere labour or exercife excites a degree of fever; and that fever is increafed by fpirits or fermented liquor of any fort; but vinegar, at the fame time that it prevents mifchief from drinking cold water during the heat and perfpiration occafioned by exercife, allays the fever; and the labourers found themfelves more refrefhed and lefs exhaufted at night, when vinegar was ufed inftead of rum.

The exact proportion of the vinegar is not known by the writer, but it is fuppofed that it was not more than about a tea-fpoonful to half a pint of water.

The difcovery, it is faid, was not altogether new, as the Romans ufed vinegar to mix with water for the drink of their foldiers.

The writer of the above agricultural report adds to this, that M. Denon, a celebrated French draughtfman, who accompanied their army while it was in Upper Egypt, experienced the advantage of vinegar mixed fomewhat in this way in that burning climate, which he relates in this manner: "I cooled the heat of my blood with vinegar, which I mixed with water and fugar, and drank of it largely."

Independently of this, however, the fame writer ftates, that the quality of water, which produces the ill effects above defcribed to perfons drinking it cold, when under any confiderable degree of perfpiration, may probably be corrected by the fimple addition of fkim-milk. The labourers in fome diftricts of this kingdom, it is faid, during harveft, make ufe of no other beverage than milk and water, which is found to allay the fever, and quench the thirft, much more than beer. At the fame time, the labourers are glad when they can get beer or ale, though they confefs that they are much fooner thirfty after drinking either, than they are after drinking milk and water, or it would feem than vinegar and water.

As it is neceffary to have good and well-kept vinegar in this intention, as well as for fome domeftic and other purpofes, it may be proper to confider the nature of it, and the means of preferving and preventing the decompofition and injury of it in any way. Where good vinegar is wanted, wines of good quality are neceffary, as the beft kinds of it are thofe that have been made from generous wines. The more fpirituous the wine is, and the more of this vinous fpirit that can be retained in the vinegar, of courfe the better and ftronger it will be, and confequently the more fit for the above ufes. In regard to the means of its prefervation, they principally confift in defending it well againft the action or influence of the external air, by keeping it in proper veffels, well clofed, and placed in cool fituations. Its alterations and injuries may likewife be further retarded, where neceffary, by depriving it of a portion of the water which it contains; for which purpofe, nothing more is wanted than to juft let it boil for an inftant; but the veffels which are employed in this kind of bufinefs fhould obvioufly not be made of copper. The procefs too, which has been propofed by fome with a fimilar intention, is quite fimple; it confifts in filling with this acid glafs veffels of a proper kind, which are to be then placed in boilers full of water; the water being in this cafe made to boil for a full quarter of an hour, after which the vinegar in the veffels is taken out, when it may be kept for feveral years without undergoing any alteration or decompofition. Diftillation, too, has been advifed as a means of preferving vinegar; but befides the circumftance of its being a tedious and difficult procefs, it is apt to deprive the acid of the agreeable fmell and tafte which are peculiar to it in its natural ftate, and which is always defirable, but more efpecially when for ufe in the above intention. And the fame is the cafe with vinegar that has been concentrated by freezing. The acid by this fimple operation becomes much ftronger, and capable of being kept for a much greater length of time; but it acquires fomething of a burnt fmell and tafte, which render it unfit for being employed for many domeftic purpofes, as well as that above ftated.

There is another manner of accomplifhing this bufinefs by a faline fubftance, which is that of fea-falt, or muriate of foda, which is advifed by fome to be added to vinegar, as being able to preferve it, and which fucceeds well enough in fome cafes, though it is not without its inconveniences; for the vinegars that contain this material grow turbid, and at length lofe their primitive qualities. But though it may not fucceed quite fo perfectly as might be wifhed, it may ftill be employed in certain cafes with advantage, efpecially if the quantity of falt that is neceffary to be added to the vinegar be not in too large a proportion.

What refpects the figns by which vinegar may be known to be good, adulterated, or fpoiled, deferve confiderable attention, as nothing is more common than to meet with vinegars that are of bad quality. Two caufes principally contribute to their being in that ftate: the firft of which is, that they have been manufactured or prepared with weak wines, or fuch as are already in a fpoiled condition; the fecond, that they have been mixed with acrid fubftances, fuch as pimento and others; or that mineral acids, fuch as the fulphuric or muriatic, have been added to them. Nothing is, however, more eafy than to detect fuch frauds and impofitions, it being fufficient for the purpofe to merely faturate a given quantity of potafh with the vinegar which is

ſuſpected of adulteration, and to compare the quantity of vinegar that has been obliged to be employed before a complete ſaturation could be obtained, with that conſumed in a ſimilar trial made with vinegar, the good quality of which is well known; and by evaporating or reducing the ſubſtance of the ſolution nearly to dryneſs afterwards, the nature of the material employed may be aſcertained. And as to the acrid vegetable ſubſtances that may have been mixed with it, they may be readily recognized by their taſte, which will be altogether different from that of the vinegar, and which will become the more perceptible, the more the acid has been concentrated or reduced by evaporation, or any other means.

It may be noticed in general, that vinegar which has not been adulterated, or which has not been ſpoiled by an incipient decompoſition, is readily and eaſily known by its penetrating acid taſte, its tranſparency, and its agreeable ſmell, which becomes ſtill more developed if ſome of the vinegar be rubbed between the hands, or in any other way.

In ſome of theſe modes, vinegar that is fit for uſe in the above intention, and for other purpoſes, may be readily known.

Vinegar is frequently alſo of much utility and advantage as an application in different caſes of bruiſes and ſlight ſwellings, ariſing from blows and other accidents among different kinds of live-ſtock or domeſtic animals.

VINEGAR *of Antimony*, is an acid ſpirit, beſt made by diſtillation from the ore of antimony. See ANTIMONY.

Its uſe is recommended in continued and malignant fevers.

VINEGAR, *Aromatic*, of the Edinb. Ph., is prepared by taking of roſemary tops dried, and ſage leaves dried, of each 4 oz.; lavender flowers dried, 2 oz.; cloves bruiſed, 2 dr.; and diſtilled vinegar, 8 lbs.: macerating theſe ingredients for ſeven days, and filtering the expreſſed liquor through paper. The odour of this liquid, which is a ſolution of the volatile oils of the ſubſtance employed in vinegar, is pleaſant, pungent, and aromatic; and it is a grateful perfume in ſick rooms, but cannot be regarded as a prophylactic from fever, or other contagions.

The aromatic ſpirit of vinegar, originally invented and ſucceſſively improved by the late ingenious and reſpectable Mr. Henry of Mancheſter, is compoſed of highly concentrated vinegar, joined with the moſt pleaſant aromatic and efficacious antiſeptics, and may be kept unimpaired for any length of time, and in any climate. Its fragrant odour adapts it for affording relief in head-aches, faintings, &c. and renders it peculiarly grateful and refreſhing in crowded rooms, places of public reſort, and the apartments of the ſick. It is alſo ſaid to counteract the infection of contagious diſeaſes.

VINEGAR, *Diſtilled*, is the ſpirituous acid of vinegar obtained by diſtillation. The proceſs of diſtilling vinegar is very ſimple. A quantity of good ordinary vinegar is put into a large cucurbit or ſtill, which ought to be made of ſtone-ware, and not of metal, as the acid of vinegar is capable of acting upon moſt metals. This cucurbit is ſunk in a deep furnace, ſo that five or ſix fingers' breadth only near its neck appear. The neck is to be carefully luted with clay all round the furnace, that the capital may not be heated too much. A capital and a glaſs receiver are then to be fitted, and the diſtillation is to be begun with a very gentle heat. The acid ſpirituous liquor paſſes by drops into the receiver. This liquor is white, tranſparent, penetrating, ſomewhat empyreumatic, and diſengaged from an acid, but not ſpirituous ſubſtance, and alſo from an extractive ſaponaceous matter, both which are contained in ordinary vinegar. Theſe latter ſubſtances remain in the ſtill with the colouring matter, and form together an extremely acid extract of vinegar. This reſiduum contains alſo ſome tartar, and by incineration yields much fixed alkali, as all matters belonging to vines, grapes, and wine do.

The thicker vinegar is, the leſs fit it proves for diſtillation, as there is always the greater danger of an empyreuma, or burnt ſmell, which would ſpoil the whole proceſs, and as it uſually in this caſe comes over oleaginous. And the pureſt white ſalt of tartar, ſaturated with this diſtilled vinegar, being afterwards ignited, turns black, and yields a ſmell extremely like that of crude tartar in the calcination. Shaw's Chemical Eſſays.

On the other hand, the more the vinegar is diluted immediately before diſtillation, the leſs danger there is of burning; and if the thick remaining maſs, when the thinner part is diſtilled from it, be again diluted with water, it may, by a ſecond diſtillation, be brought to afford an acetous ſubſtance; though this latter be by no means comparable to this former volatile part. This Vigani juſtly ſuſpects to be a circumſtance known but to very few. And even when the vinegar is diſtilled with the utmoſt labour and care, it ſtill has this effect in a higher degree, and contains an immenſe quantity of phlegm, in proportion to its acid ſalt.

In this caſe, the method of condenſation by freezing is of the utmoſt ſervice; firſt of all ſeparating the more aqueous part, and in the next place that which is ſomewhat acetous, though not comparable to what remains behind; ſo that, by this means, a moſt concentrated and ſubtle ſpirituous diſtilled vinegar may be produced, *viz.* by freezing the whole parcel of diſtilled phlegm and diſtilled vinegar together, a thing of great moment to the curious in the *chemia ſublimior*, and particularly to thoſe who underſtand Hollandus. And when the vinegar is froze without diſtillation, by this means you have a noble rob, or a rich concentrated vinegar, freed from its diſtillating aqueous and uſeleſs part. Vigani, Medull. Chem.

The Lond. Ph. directs the acetic acid to be diſtilled from a gallon of vinegar in a glaſs retort, placed in a ſand-bath, into a glaſs receiver kept cool; the firſt pint to be thrown away, and the ſix ſucceeding pints which are diſtilled to be preſerved. The diſtilled acetous acid of the Edinb. Ph. is prepared by diſtilling 8 lbs. of the acetous acid in glaſs veſſels, with a gentle heat, rejecting the 2 lbs. which firſt came over, as being too watery; and the 4 lbs. that follow will be the diſtilled acetous acid: the reſidue is a ſtronger acid, but too much burnt. The diſtilled vinegar of the Dub. Ph. is obtained by taking of wine vinegar ten pints, and diſtilling with a gentle heat ſix pints: the diſtillation is to be performed in a glaſs veſſel, and the firſt pint which comes over rejected. The ſpecific gravity of this acid is to that of water as 1006 or 10095 to 1000. (See ACETOUS *Acid.*) Darracq has aſcertained (Annales de Chimie, xli. 264.) that diſtilled vinegar differs from acetic acid, by containing ſome uncombined mucilage and extractive matter, but that the acids are otherwiſe the ſame. To this extractive it is owing, that when diſtilled vinegar is boiled with potaſs, the ſolution has a deep reddiſh-brown colour, and during evaporation carbonaceous matter is depoſited. Sulphuric acid is detected by a precipitate being produced on the addition of a ſolution of acetate of barytes; lead, by a ſolution of ſulphuretted hydrogen, forming a dark-coloured precipitate; and copper, by its aſſuming a blue colour, when ſuperſaturated with ammonia. The medical properties and uſes of diſtilled vinegar are the ſame with thoſe of common vinegar; but, being purer, and leſs

liable to ſpontaneous decompoſition, it is fitter for pharmaceutical purpoſes. Thomſon's Diſp.

VINEGAR, *Concentrated.* See CONCENTRATION.

VINEGAR *of Lead*, is a liquor formed by digeſting ceruſſe or litharge, with a ſufficient quantity to diſſolve it perfectly. This is called the *acetum lithargyrites*, and is prepared by digeſting four ounces of litharge about three days in a ſand heat, with a pint of ſtrong vinegar, now and then ſhaking the veſſel. The liquor, filtered, will receive a ſtrong impregnation from the litharge, and will be found to have diſſolved about one-tenth of it. When a ſaturated ſolution is required, the ceruſſe is preferred to the litharge. This vinegar is of the ſame nature with ſolutions of ſaccharum ſaturni, and when diluted with a large quantity of water, it abates external inflammations, the itching and other uneaſineſſes in cancerous ulcers; and before Mr. Goulard's practice, it was uſed for bathing inflammations in ſcirrhous tumours, to prevent their becoming cancerous. Inflammations and inflammatory tumours, in general, are diſperſed by it. Dr. William Saunders has obſerved, that the acetum lithargyrites, or Goulard's extract, is not the ſame in its operation and powers as the ſaccharum ſaturni, as medical practitioners have generally ſuppoſed. In the preparation of the former, the acid is fully ſaturated with lead; but in that of the latter, the acid is in a much greater proportion to the lead. The former, when diluted by the pureſt diſtilled water, gives out a copious precipitation, which he finds, by experiment, to be ceruſſe. The latter remains diſſolved in diſtilled water, and is, therefore, applied topically in a ſtate more immediately active, both on account of its greater proportion of acid, and its preſerving its ſolubility under high degrees of dilution. He has alſo found by experiment, that, by adding a very ſmall proportion of diſtilled vinegar to the aqua ſaturnina of Goulard, the white precipitate is rediſſolved, and that the ſolution procured in this manner is more active, but leſs adapted to remove inflammation, and abate irritation, as a ſedative, than the aqua ſaturnina itſelf. Dr. Saunders, however, is perfectly convinced that no degree of dilution of ſaccharum ſaturni will anſwer the many valuable purpoſes obtained from the uſe of the acetum lithargyrites. Water alone, in the caſe of the aqua ſaturnina, proves a precipitant of lead, by attracting the acid, and reducing the preparation to a ſtate of ceruſſe, an intermediate ſtate between lead and the ſaccharum ſaturni; ſo that ceruſſe diffuſed in water more nearly reſembles the aqua ſaturnina of Goulard, than a ſolution of the ſaccharum ſaturni does. The ſaccharum ſaturni may be conſidered as an union of ceruſſe with vinegar; whereas Goulard's acetum lithargyrites is an union of lead with vinegar. See Percival's Phil. Med. and Exp. Eſſ. 1776. Append. p. 323, &c. See alſo LEAD.

VINEGAR *of Meadow Saffron*, *Acetum Colchici*, is ordered by the London College to be prepared by taking of the meadow ſaffron root (bulb) ſliced, 1 oz.; of acetic acid, a pint; and of proof-ſpirit, a fluid-ounce; macerating the root with the vinegar in a covered glaſs veſſel for twenty-four hours, then expreſſing, and ſetting the liquor aſide, that the feculencies may ſubſide, and adding the ſpirit to the clear liquor. This is given as a diuretic in aſcites and hydrothorax, but is leſs to be depended on than the ſquill. The doſe is from f℥ſs to f℥j, united with honey, or any bland fluid. See COLCHICUM and *Meadow* SAFFRON.

VINEGAR, *Portable*, a name given by the chemiſts to a ſort of vinegar-powder, or vinegar in a dry form. It is a preparation of tartar with vinegar, and is made in this manner: Take white tartar, half a pound; let it be carefully waſhed, then dried and powdered; infuſe this powder in the ſtrongeſt wine-vinegar; then dry it, and infuſe it again, repeating this operation ten times: after this the dry powder is to be kept for uſe. At any time, a ſort of extemporaneous vinegar may be made by diſſolving a ſmall quantity of this powder in any proper liquor.

VINEGAR, *Prophylactic.* See ACETUM *Prophylacticum.*

VINEGAR, *Radical*, is a name given to the acid of vinegar, highly concentrated, by diſtilling verdigris, or cryſtals of verdigris, &c. See ACETIC *Acid.*

M. de Laſſone has lately found, that in the proceſs of diſtilling verdigris for this purpoſe, a fluid eſcapes of the nature of thoſe called by the ancient chemiſts *gas*, and by the moderns *fixed air;* and he alſo obſerved, that if the diſtillation be ſuſpended the moment before the acid concentrated vapours appear under a white form, copperiſh flowers are obtained: before this period, the radical vinegar contains no copper; it only begins to contain ſome, when the copperiſh flowers, carried along by the acid vapours, mix themſelves with this vinegar: if it is then rectified by a new diſtillation, theſe flowers are no more ſublimed, and, therefore, a radical vinegar, exempt from copper, may be extracted from verdigris. The copperiſh flowers are in a high degree cauſtic, and may be conſidered as a violent poiſon. Hiſt. Acad. Sc. Par. 1777.

VINEGAR *of Roſes.* See ACETUM *Roſatum.*

VINEGAR *of Squill.* See SQUILL.

VINEGAR, *Eels in.* The common opinion, from the diſcovery of eels in vinegar, that its ſharpneſs to the taſte was occaſioned by theſe animals, cauſed the accurate Leeuwenhoeck to attempt a careful examination of it by the microſcope.

Some of the ſtrongeſt and ſharpeſt vinegar, after having been expoſed for ſome hours to the air, and afterwards examined by the microſcope, entertains the ſight with a number of corpuſcles, called the ſalts of vinegar, which are acute at both extremities, and have many of them in the middle an oblong figure of a browniſh colour, and others were altogether clear, pellucid, and bright as cryſtal. Others of theſe particles appeared of an oval figure, and ſome of the half of ſuch a figure, hollowed like a ſmall boat, or the half of a nut-ſhell. The more perfect figures, pointed at both ends, and pellucid, are ſo very minute, that ſome thouſands of them are comprehended in a ſmall drop.

Theſe ſeem to be what affect the tongue with the acid ſharpneſs, when we taſte vinegar; and it is very probable, that beſide theſe, minute as they are, there are multitudes of others, equally pointed, and infinitely ſmaller than theſe.

If vinegar be placed in an open glaſs, and ſuffered to remain ſome weeks, the ſurface of it will be found, on examination with good glaſſes, to be full of the ſame figures, double-pointed, and very pellucid; and in theſe, very often, there may be cavities plainly diſcovered; but examining the liquor a little deeper down, there are found numbers of minute eels; yet theſe, though minute, are prodigiouſly larger than the ſalt particles, and can never be ſuppoſed to be the occaſion of the ſharpneſs of vinegar to the taſte, by any who rightly conſider, ſince it is not all vinegar that contains them; nay, the much greater part of vinegar is wholly without them, and in winter they all die; yet vinegar is not leſs ſharp at that ſeaſon than in the ſummer.

Mr. Mentzelius was ſo lucky as to ſee theſe undergo their laſt metamorphoſis, and change into ſmall flies; and though this is a ſingle inſtance, in regard to the microſcopical world of animalcules, yet it is highly probable that the whole race of thoſe, whoſe appearance in medicated fluids we have been ſo long puzzled to account for, may, like theſe, be the worm-ſtate of ſome winged aerial inſect, and have owed

their origin, where we ſee them, to the eggs of parent flies, too ſmall for our ſight. Reaumur, Hiſt. Inſ. vol. iv.

If vinegar be impregnated with crab's-eyes, or any other alkaline ſubſtance, which blunts, and in a great meaſure deſtroys its acidity, theſe double-pointed figures are no longer found in it, on a microſcopical inſpection; but in their places we find others with an oblong quadrangular baſe, from which they ſhoot up into pyramids, and appear like poliſhed diamonds. Theſe are alſo ſo very minute, that ſix thouſand of them are computed to be contained in a drop of the liquor, no larger than two corns of barley; and theſe will be uſually found all of the ſame ſize, or very nearly ſo, which is by no means the caſe with the other ſorts of vinegar in its natural ſtate. See *Microſcopic* EELS.

Vitriol

VITRIOL, Native, in *Mineralogy*, is a fubftance of greyifh or yellowifh-white, apple or verdigris-green, or fky-blue colour; and when decompofed, covered with an ochrey cruft. It occurs in mafs, difseminated, ftalactical, and capillary. Externally it is rough and dull; internally it is more or lefs fhining, with a vitreous or filky ftructure. Its fracture is generally fine and ftraight fibrous, fometimes alfo lamellar and conchoidal. It is foft, brittle, and tranflucent, and has an acerb metallic flavour. It is more or lefs foluble in water, and is a mixture in various proportions of the fulphate of iron, copper, and zinc. It is not unfrequently found in caverns and fhafts, in argillaceous fchiftus, and in old mines, efpecially fuch as abound in blende and pyrites. Aikin.

Some take the word *vitriolum* to be ufed *quafi vitri oleum,* becaufe of its fhining colour; but Menage rather derives it *à vitreo colore:* the Latins call it *atramentum futorium;* and the Greeks, *chalcanthus*.

It acquires different names, according to the different places where it is dug; and the vitriols of thofe alfo differ from each other in denomination and colour; fome being *white*, others *blue*, and others *green*.

Roman and Cyprus vitriol, for inftance, is blue; and that of Sweden and Germany, commonly called Englifh vitriol, is green; befides which there is alfo a white kind, called Goflar vitriol.

Vitriol is very commonly called by the manufacturers copperas; accordingly, we conftantly hear of green, blue, and white copperas. The conftituent parts of the different kinds of vitriols were not underftood by the ancients fo well as they are at prefent: they feem to have had an idea, that copper was the bafis of them all: hence the Greek term for vitriol, *chalcanthus*, the efflorefcence of copper, and the Latin one, *cuperofa* or *cupri rofa*, the flower or efflorefcence of copper; from which, fays Dr. Watfon, the French *couperofe*, and our copperas, are evidently derived. See Cabrusi.

Some moderns take the *chalcitis*, or *chalcanthum* of the ancients, which they fuppofed to be a native vitriol, that had acquired, according to their opinion, its full perfection in the entrails of the earth, and which is a kind of mineral ftone, of a reddifh colour, to be the fame with that chalcanthum brought from Sweden and Germany; the beft of which is of a brownifh-red colour, and a vitriolic tafte, and diffolves eafily in water; and when broken, is of the colour of fhining copper. See Vitriolic *Minerals*.

The vitriols which nature prepares are never to be met with in commerce; they ferve to adorn the cabinets of the curious, but they are neither fufficiently pure for the purpofes to which common vitriols are applied, nor are they found in fufficient quantities to anfwer the demand which is made for them.

Vitriol, in *Chemiftry*, is a term that is now applied to every combination of the acid of fulphur with any metallic fubftance: three of thefe combinations, however, are more particularly diftinguifhed, being of great ufe in various manufactures; *viz. green vitriol* or *fulphate of* Iron (which fee), *blue vitriol* or *fulphate of copper* (fee Copper and Copperas), and *white vitriol* or *fulphate of zinc.* (See Zinc.) The acid in all thefe vitriols is the fame; the metallic bafis of the green vitriol is iron, that of the blue vitriol is copper, and that of the white vitriol, zinc.

According to the analyfis of fir Torbern Bergman, (Effays, by Cullen, vol. i. p. 180.) 100 parts of blue vitriol, or vitriolated copper, cryftallized, contain 26 of copper, 46 of vitriolic or fulphuric acid, and 28 of water. According to Kirwan, 100 parts contain 30 of real acid, 27 of copper, and 43 of water. The tafte is acefcent, æruginous, and cauftic; it calcines in heat; one part, in a moderate heat, requires nearly four parts of water, but much lefs of boiling water. Of white vitriol, or vitriolated zinc, 100 parts contain 20 of zinc, 40 of vitriolic acid, and 40 of water. According to Kirwan, 100 parts contain 22 of acid, 20 of zinc, and 58 of water. In a moderate heat, one part requires more than two of water, but much lefs of boiling water. Its tafte is acefcent, aftringent, and cauftic. Of green vitriol, or vitriolated iron, 100 parts contain 23 of iron, 39 of vitriolic acid, and 38 of water. According to Mr. Kirwan, 100 parts of it, recently cryftallized, contain 20 of real acid, 25 of iron, and 55 of water. In moderate heat, one part requires fix of water, but three-fourths of boiling water. In heat it fplits into a yellow powder; in the fire, into a ferruginous powder. The tafte is acefcent, ftyptic, and cauftic.

Green vitriol is often met with native in our coal-mines. From an old cannel coal-pit, near Wigan in Lancafhire, Dr. Watfon procured a confiderable quantity of it, very well cryftallized; and Dr. Rutty has obferved, that the vitriolic water at Haigh, in Lancafhire, is the ftrongeft in Britain, yielding 1920 grains of vitriol from a gallon of water. See Vitriolic *Waters*.

The *green vitriol*, or fulphate of iron, commonly called Englifh vitriol or copperas, and the Roman vitriol of the Italian writers, is prepared at Deptford, near London, and many other places, from martial pyrites, which is a native fulphuret of iron, and is found in abundance on Sheppey ifle, the ifle of Wight, and various other parts of the Effex, Kentifh, Suffex, and Dorfetfhire coafts. By expofing this to the air in large beds, oxygen is abforbed; the fulphur becomes fulphuric acid, and the new-formed falt is feparated by wafhing, &c.

Much after the fame manner vitriol is made from the pyrites found among coal: there are manufactories of it near Wigan, at Whitehaven, at Newcaftle-upon-Tyne, and in

ſeveral other parts of the kingdom. But all the vitriol works have ſunk in value of late years; the home conſumption of vitriol being much diminiſhed, ſince the acid, which uſed to be procured from the diſtillation of vitriol, has been obtained from the burning of ſulphur. For the ancient and modern method of obtaining this acid, we refer to the article SULPHURIC *Acid*.

It is not eaſy to determine when this method of making vitriol was introduced into England. In the beginning of the reign of queen Elizabeth, a patent was granted to Cornelius Devoz for making alum and copperas; but it was not till towards the end of the 17th century, that this art of making vitriol was brought to ſo great a perfection as to enable us to export any of it; and indeed Dr. Campbell (Surv. of Brit. vol. ii. p. 21.) aſſures us, that at the latter end of the 17th century we imported annually about five hundred tons of vitriol, and that we now export upwards of two thouſand tons. It appears from ſir Charles Whitworth's Regiſter of Trade, N° 1, that there were exported, from the port of London alone, near four hundred tons of copperas in three months, in 1776. A ſmall quantity of vitriol, perhaps to the annual amount of fifty or ſixty tons, ſays Dr. Watſon, is ſtill imported into England; ſome particular dyers, and other artiſts, being of opinion, that the foreign vitriol, as containing a little copper, is more uſeful to them than the Engliſh vitriol. It may be eaſily known whether green vitriol contains any copper, by only rubbing the vitriol to be examined upon a moiſtened piece of poliſhed iron; for if there is any copper in its compoſition, the iron will be changed into a copper colour.

Vitriol is alſo prepared from mineral waters that hold copper in ſolution, which is precipitated by iron: this ſolution of iron is afterwards cryſtallized, and always retains ſome copper. In Hungary it is prepared from pyritaceous ſchiſtus, and in many places from a ſpecies of calamine; the vitriol of Goſlar commonly contains a portion of zinc, as that of Hungary and Saxony does of copper; the Engliſh and French vitriols are purer, and yet ſometimes contain a ſmall proportion of alum. Turf and peat are ſometimes impregnated with vitriol; other earths alſo often contain vitriol and alum. This vitriol is ſometimes found of a white colour, on the borders of the mineral lakes of Tuſcany.

Pure vitriol of iron is conſiderably tranſparent, of a fine bright, though not very deep, graſs-green colour; of a nauſeous, aſtringent taſte, accompanied with a kind of ſweetiſhneſs. Diſſolved, and ſet to cryſtallize, it ſhoots into thick rhomboidal maſſes, a part generally riſing at the ſame time in efflorefcences about the ſides of the veſſel. The ſolution depoſits, in ſtanding, a conſiderable quantity, and in boiling a much larger one, of the metallic baſis of the vitriol, in form of a ruſty calx or ochre: iron ſeems to be the only metallic body that thus ſeparates ſpontaneouſly, in any conſiderable quantity, from the vitriolic acid. On expoſing the vitriol itſelf to a moiſt air, a ſimilar reſolution happens on its ſurface; which, ſooner or later, according as the acid is more or leſs ſaturated with the metal, changes its green to a ruſty hue. In a warm dry air, it loſes a part of the phlegm or water, neceſſary to its cryſtalline form, and falls by degrees into a white powder. Expoſed to a gentle fire, it liquefies and boils up; but ſoon changes, on the exhalation of the watery part that rendered it fluid, to a ſolid, opaque, whitiſh, or grey maſs: this pulverized, and urged with a ſtronger fire, continues to emit fumes, becomes yellow, being the *vitriolum calcinatum* of the London and Edinburgh Diſpenſatories; afterwards red, and at length turns to a deep purpliſh-red calx, called *colcothar of vitriol*, and the *chalcitis factitia* of the Paris Pharmacopœia, revivable by inflammable ſubſtances into iron. This colcothar was formerly ſold at Paris for ten-pence a pound, and uſed for giving the laſt poliſh to plate-glaſs, at the great manufactory in the ſtreet St. Antoine. The plate of glaſs, when firſt caſt, is an inch thick; its aſperities are ground away with a coarſe kind of grit-ſtone, with ſand and emery, of different degrees of fineneſs, and it is at laſt poliſhed by colcothar. Dr. Watſon ſuggeſted to the proprietors of the plate-glaſs manufactory, near Preſcot, in Lancaſhire, and to the patentees for poliſhing marble, at Aſhford, in Derbyſhire, that colcothar, which is very cheap, might perhaps render the uſe of putty, or calcined tin, leſs neceſſary. From the colcothar of vitriol is prepared the *ens veneris*.

From the green vitriol the vitriolic acid, now called ſulphuric acid, has been generally extracted; by diſtilling the calcined vitriol in earthen long necks, with a ſtrong fire continued for two days or longer; though it is now moſtly obtained by collecting the vapour of burning ſulphur.

The diſtilled ſpirit appears of a dark blackiſh colour, and contains a quantity of phlegm, greater or leſs, according as the vitriol has been leſs or more calcined. On committing it a ſecond time to diſtillation, in a glaſs retort placed in a ſand-heat, the phlegmatic parts riſe firſt, together with a portion of the acid, and are kept apart under the name of *ſpirit*, or *weak ſpirit of vitriol*, *ſpiritus vitrioli tenuis* of the London Diſpenſatory: at the ſame time, the remaining *ſtrong ſpirit*, or *oil*, as it is called, loſes its black colour, and becomes clear; in which ſtate it is the *acidum vitriolicum* of the Edinburgh Diſpenſatory, and the *ſpiritus vitrioli fortis* of that of London; and this is the uſual mark for diſcontinuing the rectification.

The College of Edinburgh now directs a weak vitriolic acid of more certain ſtrength, made by mixing one part of the ſtrong acid with ſeven parts of water: this is called *acidum vitriolicum tenue*, vulgò *ſpiritus vitrioli tenuis*. See SULPHURIC *Acid*.

Blue vitriol, or vitriol of copper, is commonly called Roman or Cyprian vitriol, or blue-ſtone. After being long expoſed to the air, it degenerates into a mixture of blue and ruſty yellow. It requires about four times its weight of water to diſſolve it in the temperature of 60°. Its ſpecific gravity is about 2.23. This ſalt rarely occurs cryſtallized, but is often found naturally diſſolved in water, in Hungary, Sweden, and Ireland; from which water blue vitriol is generally prepared, by evaporating the water to a proper ſtandard; after which it is let out into coolers, where it ſhoots into regular and beautiful cryſtals of a rhomboidal form. See ZIMENT *Water*.

It is alſo occaſionally extracted from ſulphurated copper ores after torrefaction, by the application of water, or waſhed out by rain or ſubterraneous waters. Mr. Cronſtedt ſays it is ſeldom free from iron and zinc. If a piece of clean poliſhed iron be dipped into the ſolution of this ſalt, it will almoſt immediately be covered with a cupreous coat: this, together with the deep blue colour ariſing from mixing it with a volatile alkali, diſcovers its baſis; as its uniform mixture with other vitriolic ſalts does its acid. Hence it alſo appears, that the acid of vitriol has a greater affinity with iron than with copper, becauſe it quits copper to unite itſelf with iron. This fact explains, in a very ſatisfactory manner, the nature of that tranſmutation of iron into copper, which was formerly conſidered as a perplexing phenomenon. Agricola ſpeaks of waters in the neighbourhood of Newſol, in Hungary, which had the property of tranſmuting the iron which was put into them into copper. In the year 1673, our countryman, Dr. Brown, viſited a famous copper-mine at Herrn-Grundt, near Newſol; and he informs us,

that he there saw two springs, called the old and new Ziment, which turned iron into copper. The iron in this case is taken up by the water, and remains suspended in it, in the place of the copper: so that this transmutation is nothing but a change of place; and as the copper is precipitated by the iron, so the iron might be precipitated by pot-ash, or any other substance which has a greater affinity with the acid of vitriol than iron has.

The cause of the impregnation of these copper waters in Germany is not difficult to be explained. Most copper-ores contain sulphur, and when the sulphur is in any degree decomposed, its acid unites itself to the copper, and forms blue vitriol, which is the substance with which the waters issuing from the copper-mines are impregnated. The copper contained in these waters has been for some centuries collected in Germany, by putting old iron into pits filled with the coppery water; and thus the iron is dissolved, and the copper is precipitated, and being raked out in the form of mud, it is afterwards melted into very fine copper. The quantity of copper procured by an hundred tons of iron amounts sometimes to ninety tons, and seldom to less than eighty-four. Of late years some successful attempts of this kind have been made in England and Ireland. See Copper.

In the Isle of Anglesey, near Paris mountain, which abounds in copper ore, the water in which the roasted ore is washed is so strongly impregnated with copper, that they have found it useful to adopt the German method of precipitating it by means of old iron, and they have obtained in one year near a hundred tons of copper, precipitated from this water. The water, after the copper has been precipitated by means of iron, is at present thrown away; whereas, by evaporation, it would yield green vitriol; and as above a hundred tons of iron must be employed in obtaining the forementioned quantity of copper, Dr. Watson suggests, whether a manufactory of green vitriol might not be established at this and at all other places where copper is obtained by precipitation. One hundred tons of iron would yield, at the least, two hundred tons of vitriol, which, at the low price of 3*l.* *per* ton, would defray the expence of extracting it; more especially as the watery solution might be evaporated by a proper application of part of that heat, which is now lost in all the great smelting houses.

The greatest part of the blue vitriol, now met with in the shops, is prepared in England, by artificially combining copper with its sulphur or its acid. The method of making the preparation by the glass-makers is this: Take little thin pieces of brass, and lay them stratum super stratum in a crucible, with powder of brimstone. When the vessel is full, let it luted and covered in an open wind-furnace, with burning coals over it, and let it stand two hours; then let the furnace cool of itself, and take out the crucible, the mass within will be of an obscure blackish-purple; powder it and sift it fine, and then mixing with every pound of it six ounces of powdered brimstone, take a round vessel of earth, that will bear the fire, place it upon iron bars set across in an open wind-furnace, fill it with coals, and then put in the powder; keep it burning and stirring about till all the brimstone is burnt up; then take out the pan, and powder the calcined mass again; sift it fine, and proceed with it thrice as before; the last time let it stand on the fire till it becomes red. Put a pound of this calcined copper into a glass body, with six pints of water; evaporate two pints or thereabout in a sand heat; the water is then of a fine blue, and must be poured off clear; then filtrate it. Evaporate the water from the remaining sediment of copper left in the glass, and with new sulphur calcine it again and again; repeat this five or six times, and extract the blue tincture with water as before; filtrate all the waters, and put them together. Evaporate all to a fifth part, or thereabouts, and set it in a cool place, and fine pointed crystals will be formed, resembling emeralds; separate these crystals, and evaporate the water again, till all the crystals be procured. Then put a pound of them into a glass retort, well luted, and fitted to a capacious receiver; let the joints be well closed, and make a moderate fire for four hours; then make it violent for twenty hours, or till no more white fumes arise. The next day open the receiver, and separate the liquor into a glass, where it must be kept carefully sealed up. Neri's Art of Glass, p. 50.

Very great things are to be done in the glass art by means of this liquor; the remainder in the retort exposed to the air for a few days, will acquire a blue colour, and this, mixed with zaffer, will give glass a fine sea-green. The vitriol of copper is of an elegant sapphire blue colour; hard, compact, and semitransparent; when perfectly crystallized, of a flattish, rhomboidal decahedral figure; in taste extremely nauseous, styptic, and acrid. Exposed to a gentle heat, it first turns white, and then of a yellowish-red or orange colour; on increasing the fire, it parts, difficultly, with its acid, and changes at length to a very dark red calx, reducible, by fusion with inflammable fluxes, into copper.

Some writers hold vitriol to be the root or matrix of copper; because, in the copper-mines, they never dig deeper than the glebe, out of which the vitriol is drawn. For the use of blue vitriol in medicine, &c. see Vitriol, in *Medicine*.

The *white vitriol*, or vitriol of zinc, is found native in the mines of Goslar, sometimes in transparent pieces, more commonly in white efflorescences; which are dissolved in water, and crystallized into large irregular masses, somewhat resembling fine sugar; it is also found dissolved in mineral waters, and generally with some proportion to the vitriol of iron and copper: it is in taste sweetish, nauseous, and styptic.

It has been disputed, whether white vitriol is any thing else than green vitriol calcined. But it seems that white vitriol is of a quite different species from either the green or the blue vitriols. Geoffroy, Mat. Med. tom. i. p. 124.

In the condition in which white vitriol is usually bought, it contains somewhat both of copper and iron; but being purified by solution, filtration, and crystallization, it is freed from both these metals, and appears to be a native vitriol *sui generis*. See Cramer, Elem. Art. Docim. vol. i. p. 302. ed. 2. Med. Ess. Edinb. Abr. vol. ii. p. 472.

If four ounces of alum be put in concoction with two parts of cadmia fossilis pulverized, the earth of the alum precipitates, and its acid takes hold of the earth of zinc, so that a true white vitriol is the result.

This vitriol being precipitated by an alkaline ley, and dried, after its salts are separated in water, and then mixed with charcoal-dust, will give zinc.

The same thing happens in mixing vitriol of iron with two or three parts of lapis calaminaris; but the operation is easier with alum and vitriol of copper. Marggraaf, in Mem. de l'Acad. de Berlin, 1746.

The white vitriol requires little more than twice its weight of water to dissolve it in the temperature of 60°; its specific gravity is about 2.000. It mixes uniformly with vitriolic neutral salts, but precipitates nitrous or marine selenites from their solutions, which ascertains its acid principle; it is itself precipitated whitish by alkalies and earths, but not by iron, copper, or zinc, which sufficiently indicates its basis: if it contains any other metallic principle, this may be pre-

cipitated by adding more zinc, except iron, which will of itfelf precipitate by expofure to the air, or boiling in open air. That in common ufe is moftly prepared at Goflar, from an ore which contains zinc, copper, and lead, mineralized by fulphur and a little iron: the copper ore is firft feparated as much as poffible, and the refiduum, after torrefaction and diftillation, is thrown red-hot into water, and lixiviated: it is never free from iron.

The common white vitriol of the fhops contains a quantity of ferruginous matter; of which, in keeping, a part is extricated from the acid, in an ochrey form, fo as to tinge the mafs of a yellow hue. On diffolving the whiteft pieces in water, a confiderable portion of ochre immediately feparates: the filtered folution, tranfparent and colourlefs, becomes again turbid, and yellow, on being made to boil, and depofits a frefh ochrey fediment; and a like feparation happens, though much more flowly, on ftanding without heat. Hence, when the folution is evaporated to the ufual pitch, and fet to cryftallize, the cryftals generally prove foul; unlefs fome frefh acid be added (as an ounce of the ftrong fpirit or oil of vitriol to a pound of the falt) to keep the ferruginous matter diffolved: this addition fecures the whitenefs of the cryftals, and prevents their becoming foon yellow in the air. White vitriol generally contains alfo a fmall portion of copper diftinguifhable by the cupreous ftain which it communicates to polifhed iron immerfed in folutions of it, or rubbed with it in a moift ftate. The quantity of copper is, indeed, very fmall, and may, if it be thought neceffary, be feparated by boiling the folution for fome time, along with bright pieces of iron, which will extricate all the copper: by continued or repeated coction, the greateft part of the ferruginous matter may alfo be feparated. For the ufe of white vitriol in medicine and furgery, fee VITRIOL, in *Medicine*, infra.

VITRIOL, in *Medicine* and the *Arts*, has various applications and ufes. *White vitriol* is fometimes given, from five or fix grains to half a drachm and more, as an emetic, and appears to be one of the quickeft in operation of thofe that can be employed with fafety. Its chief ufe is for external purpofes, as a cooling reftringent and deficcative: a dilute folution of it, as fixteen grains in eight ounces of water, with the addition of fixteen drops of weak vitrolic acid, or the *aqua vitriolica* of the Edinburgh Difpenfatory, is an excellent collyrium in defluxions and flight inflammations of the eyes; and, after bleeding and purging, in the more violent ones. A folution of it with alum, in the proportion of two drachms of each to a pint of water, called the *aqua aluminofa Bateana*, is ufed as a repellent fomentation for fome cutaneous eruptions, for cleanfing foul ulcers, and as an injection in the fluor albus and gonorrhœa, when not accompanied with virulence. This vitriol is fometimes likewife employed as an errhine, and faid to be a very effectual diffolvent of mucous matters; in which intention it is recommended, in the German Ephemerides, againft obftructions of the noftrils in new-born infants. See ZINC.

Blue vitriol, like the other preparations of copper, acts, in dofes of a few grains, as a moft virulent emetic. Its ufe is chiefly external, as a detergent, efcharotic, and for reftraining hæmorrhages; for which laft intention a ftrong ftyptic liquor ufed to be prepared in the fhops, and called *aqua vitriolica cærulea*. Blue vitriol has of late been confiderably employed as an emetic by fome practitioners; and is faid to be by no means an unfafe one, as it operates the inftant it reaches the ftomach, before it has time to injure by its corrofive quality. The peculiar advantage in ufing it is reprefented to be, that it has no tendency to become alfo purgative, and that its aftringent power prevents the tone of the ftomach from being impaired after vomiting with it. It is much recommended in the early ftate of tubercles in the lungs; and the following method of exhibition directed. (See Simmons on the Treatment of Confumptions, p. 70.) Let the patient firft fwallow about half a pint of water, and immediately afterwards the vitriol, diffolved in a cupful of water. The dofe may be varied according to age, conftitution, &c. from two grains to ten, or even twenty; always taking care to begin with fmall ones. After the emetic is rejected, another half pint of water is to be drunk, which is likewife fpeedily thrown up, and this is commonly fufficient to remove the naufea. In ftill fmaller dofes, the blue vitriol has been much ufed by fome as a tonic in intermittents, and other difeafes. See COPPER and SULPHATE *of Copper*.

Pure green vitriol is in no refpect different from the artificial SAL *Martis*; which fee. It is one of the moft certain of the chalybeate medicines, fcarcely ever failing to take effect where the calces, and other indiffoluble preparations, pafs inactive through the inteftinal tube. It may be conveniently given in a liquid form, largely diluted with aqueous fluids: two or three grains, or more, diffolved in a pint or quart of water, may be taken in a day, divided into different dofes. This vitriol is ufed alfo, efpecially when calcined, as an external ftyptic: the ftyptic of Helvetius, and, as it is faid, that of Eaton, is no other than French brandy impregnated with the calcined vitriol: a drachm of the vitriol is commonly directed to a quart of the fpirit, but only a minute portion of the drachm diffolves in it. (See STYPTIC.) As French brandy has generally an aftringent impregnation from the oaken cafks in which it has been kept, the vitriol changes it, as it does the watery infufions of vegetable aftringents, to a black colour; but makes no fuch change in fpirituous liquors that have not received fome aftringent tincture. See IRON, SULPHATE *of Iron*, and TINCTURE.

The *acid of vitriol*, or fulphur (fulphuric acid), largely diluted, is the moft falubrious of all the mineral acids. It is mixed with watery infufions, fpirituous tinctures, and other liquids, as an antiphlogiftic; as a reftringent in hæmorrhages; and as a ftomachic and corroborant in weakneffes, lofs of appetite, and decays of conftitutions, accompanied with flow febrile fymptoms, brought on by irregularities, or fucceeding the fuppreffion of intermittents by Peruvian bark. In feveral cafes of this kind, after bitters and aromatics of themfelves had availed nothing, a mixture of them with the vitriolic acid has taken effect: the form commonly made ufe of is that of a fpirituous tincture; fix ounces of *oil of vitriol* are dropt by degrees into a quart of rectified fpirit of wine; the mixture digefted for three days in a very gentle heat, and afterwards digefted for three days longer with an ounce and a half of cinnamon, and an ounce of ginger; this is the *elixir vitrioli* of the Edinburgh Difpenfatory. Or, a pint of an aromatic tincture, drawn with proof fpirit, is mixed with three ounces of the ftrong acid, fo as to form the *acid elixir of vitriol* of the late London Difpenfatory: thefe liquors are given from ten to thirty or forty drops, in any convenient vehicle, when the ftomach is moft empty. (See ELIXIR.) A mixture of oil of vitriol with fpirits of wine alone, in the proportion of one part of the former to three of the latter, digefted together for fome time, has been ufed in France as a reftringent in gonorrhœas, female fluors, and fpittings of blood, under the denomination of *aqua Rabelliana*, and *eau de Rabel*. The acid of vitriol, diluted with water, has been given internally with great fuccefs in the itch. It was firft ufed for this purpofe in the Pruffian army in 1756, and has fince been much employed in feveral parts of Germany. The dofe recommended is from

an eighth to a fourth of a drachm of the pure acid twice or thrice a day. It is said to succeed equally in the dry and moist itch; and when given to nurses, to cure both themselves and their children.

When oil of vitriol, and rectified spirit of wine, are long digested together, or distilled, a part of the acid unites with the vinous spirit into a new compound, very volatile and inflammable, of no perceptible acidity, of a strong and very fragrant smell, and an aromatic kind of taste: this dulcified part, more volatile than the rest, separates and rises first in distillation, and may thus be collected by itself. The College of London directed this *spiritus vitrioli dulcis* to be made by cautiously and gradually mixing a pound of oil of vitriol, and a pint of rectified spirit of wine, and setting them to distil with a very gentle heat: that of Edinburgh ordered the same quantity of the oil of vitriol to be dropt into four times as much of the vinous spirit, and the mixture to be digested in a close vessel, for eight days, previously to the distillation, with a view of promoting the coalition of the two ingredients. The different proportions of the acid spirit to the vinous, in these prescriptions, make no material variation in the qualities of the product, provided the distillation be duly conducted; for the smallest of the above proportions of acid is much more than the vinous spirit can dulcify, and all the redundant acid remains in either case behind. The true dulcified spirit rises in thin subtile vapours, which condense upon the sides of the recipient in straight striæ; these are succeeded by white fumes, which form either irregular striæ, or large round drops like oil; at the first appearance of which, the process is either to be stopped, or the receiver changed. The spirit which these fumes afford, very different from the dulcified one, has a pungent acid smell, like the fumes of burning sulphur: on its surface is found a small quantity of oil, called the *sweet oil of vitriol* of Hoffman, of a strong, penetrating, and very agreeable smell, readily dissoluble in spirit of wine, to a large proportion of which it communicates the smell and taste of the aromatic or dulcified spirit. The College of Edinburgh, in order to secure against any acidity in the dulcified spirit, ordered it to be rectified, by mixing it with an equal measure of water, in every pint of which a drachm of salt of tartar has been dissolved, and drawing off the spirit again by a gentle heat. This College, in their last Pharmacopeia, have manifestly shewn how little they conceive the acid to enter as a constituent part of this preparation, and at the same time have directed an effectual method of preventing its presence in it. They order the *acidum vitriolicum vinosum*, vulgò *spiritus vitrioli dulcis*, to be made by simply mixing one part of vitriolic ether with two of rectified spirit. See *Sulphuric* ETHER, and SPIRIT *of Ether*.

This spirit, taken from ten to eighty or ninety drops, strengthens the stomach and digestive powers, relieves flatulencies, promotes urine, and, in many cases, abates spasmodic strictures, and procures rest. It is not essentially different from the celebrated mineral anodyne liquor of Hoffman; to which it is frequently, by the author himself, directed as a substitute. See LIQUOR *mineralis anodynus*, *Ethereal* SPIRIT, and *Compound* SPIRIT *of Ether*.

The dulcified spirit is sometimes used as a menstruum for certain resinous and bituminous bodies, which are more difficultly and languidly acted upon by pure vinous spirits. It is often mixed with aromatic and stomachic tinctures, in cases where the stomach is too weak to bear the acid elixirs abovementioned: eight ounces are commonly added to a pint of the officinal aromatic tincture; or the ingredients of the aromatic tincture are infused in the dulcified acid, instead of common rectified spirit, in order to form the *sweet elixir of vitriol*. A medicine of this kind was formerly in great esteem, under the name of *Vigoni's volatile elixir of vitriol*, prepared by macerating, in some dulcified spirit of vitriol, free from acidity, a small quantity of mint-leaves carefully dried, till the spirit has acquired a fine green colour: and to prevent the necessity of filtration, during which the more volatile parts would exhale, the mint may be suspended in the spirit in a fine cloth. If the dulcified spirit, rectified from a solution of fixed alkaline salt, be shaken with equal its quantity of a like solution, and the mixture suffered to rest, an ethereal fluid rises to the surface, and great part of the dulcified spirit may be recovered again from the remainder by distillation. Dr. Hadley obtained the largest portion of ether, by using the strongest vitriolic acid of the shops with equal its quantity, by measure, of spirit of wine, and distilling immediately by a heat sufficient to make the mixture boil. By this management, from three pints of oil of vitriol, and six pints of rectified spirit of wine, he obtained two pints and a half of the ether.

The vitriolic acid saturates a larger quantity of fixed alkaline salts than any of the other acids, and dislodges from them such other acids as have been previously combined with them. Of the strong spirit, or oil of vitriol, about five parts are sufficient for eight of the common vegetable fixed alkalies. The neutral salt thus obtained is of a bitterish taste, very difficultly soluble in water, and scarcely fusible in the fire: in small doses, as a scruple, or half a drachm, it is an useful aperient: in larger ones, as four or five drachms, a mild cathartic. This salt has been commonly prepared with the alkali obtained from tartar, and hence called *vitriolated tartar*, and sometimes *sal enixum*, and *arcanum duplicatum*. Some dilute the oil of vitriol with six times the quantity of warm water, and drop into it a solution of the alkaline salt till no effervescence ensues: others use vitriol in substance, which being dissolved in boiling water, any alkaline salt, gradually superadded, till the effervescence ceases, absorbs the pure acid, and throws down the metallic basis of the vitriol: one part of the alkali is nearly sufficient for two of the vitriol.

With the mineral fixed alkali, this acid forms compound salts of a more bitter taste, somewhat less purgative, and much easier of solution, than that with vegetable alkalies: with volatile alkalies, a very pungent ammoniacal salt, whose medicinal effects are not well known. The strong acid, boiled on argillaceous earths to dryness, corrodes a portion of them, and concretes with them into an austere styptic salt. Calcareous earths it does not dissolve into a liquid state, but may be combined with them, by precipitation from other acids, into an indissoluble concrete, seemingly of no medicinal activity. Among metallic bodies, it dissolves zinc and iron readily; copper, silver, quicksilver, lead, and tin, very difficultly: it is fitted for acting on the two first by dilution with three or four times its quantity of water: the others require the undiluted acid, and a heat sufficient to make it boil; when, the more phlegmatic parts exhaling, so much of the pure acid matter remains combined with the metals as to render them, in part at least, dissoluble in water.

The principal use of green vitriol is in dyeing, and in the making of ink. When the vitriol is dissolved in water, the iron contained in it becomes black by the addition of an infusion of gall-nuts. Mr. Lemery, the younger, in order to account for this blackness, imagines, that as the vitriol, of which ink is made, is iron dissolved by an acid, and intimately mixed with it, and as galls are an alkali or absorbent, this alkali, meeting the acids which hold the iron dissolved,

unites with them, and makes them set the iron loose; which thereupon revivifies, and resumes its natural blackness: so that in strictness we write with the iron.

In the Swedish Transactions, vitriol is recommended as a yellow for house-painting: quicklime, made into a paste with water, is to be diluted with a solution of vitriol, more or less, according as the colour is required deeper or lighter: the mixture appears of a blueish-green colour, and does not become yellow till it is dry. One part of vitriol is said to go as far as two of the dearer yellow ochre. This salt is also recommended for preserving wood, as particularly the wheels of carriages, from decay: when all the pieces are fit to be joined together, they are directed to be boiled in a solution of vitriol for three or four hours, and then kept for some days in a warm place to dry. It is said that wood by this preparation becomes so hard and compact, that moisture cannot penetrate it. For the use of vitriol in agriculture, see SULPHATE *of Iron*. See on the subject of the preceding articles, Neumann's Chem. Works, by Lewis, p. 173, &c. Watson's Chem. Ess. vol. i. ess. 6. Lewis's Mat. Med. art. *Vitriolum*. Bergman's Ess. vol. i. p. 180, &c. Kirwan's Elem. of Mineral. p. 189, &c.

VITRIOLS, *Metallic*. All metals, it is to be observed, may be converted into vitriols, by dissolving them with acid spirits, and letting them stand to crystallize.

Factitious vitriols, being only metals dissolved and crystallized in saline menstruums, are frequently called, by way of distinction, *metallic vitriols*, and *metallic salts*.

VITRIOL *of Cobalt* is found native in small pieces, mixed with a greenish efflorescence, in cobalt mines: it is difficultly soluble in water; and both it and its solution are red, which sufficiently distinguishes its basis. Its acid is known by the same taste as that of the other vitriols.

VITRIOL *of Iron*, *Vitriolum Martis*, is a preparation made by dissolving iron, or steel, in oil or spirit of vitriol; then evaporating or drawing off the moisture, and bringing the matter to crystallize, by setting it in a cool place. This is also called *sal martis*, or *salt of steel*.

VITRIOL *of Lead*. See LEAD.

VITRIOL *of Luna*, or *the Moon*, is the name given to a salt with a metallic basis, called also *Vitriol of* SILVER; which see.

VITRIOL *of Nickel* is found native, efflorescing on kupfernickel, and generally mixed with vitriol of iron. This is difficultly soluble in water: both it and its solution are of a green colour. See NICKEL.

VITRIOL *of Quicksilver*, the name of a chemical preparation of quicksilver, with acid spirits, the process of which is this: let so rich a solution of quicksilver be made in spirit of nitre, or aqua fortis, that no more can be contained; let this solution be made by the assistance of heat, and the liquor immediately afterwards poured off into a clean and cold glass. There will, on this, spontaneously shoot on the bottom of the glass a saline, white, transparent matter, from which the liquor being poured, it is found to be a sharp, moist, saline substance, or true vitriol of mercury, soluble in water, and not safe to be touched. If the liquor, poured off from this, be evaporated half way, and the remainder set in a cool place, more crystals of the same nature with the first will shoot.

Another method of making the vitriol of mercury is this: reduce to powder some decrepitated sea-salt, and with two parts of this mix one part of crude mercury; distil the whole in a glass body, with a strong fire continued five or six hours; when the vessels are cold, break them, and there will be found a solid dry mercury, sublimed to the top and sides of the body, in form of vitriol. Nay, Boerhaave affirms, that the common mercury sublimate is a true vitriol of mercury, though semi-volatile. Boerh. Chem. part ii. p. 301.

Vitriol of quicksilver is also a name given to a salt of mercury, mineralized by vitriolic acid, first discovered by Mr. Woulfe, together with the marine salt of mercury, at Obermoschel, in the duchy of Deux-Ponts: they have a sparlike appearance, and are either bright and white, or yellow or black, mixed with cinnabar in a stony matrix: these well mixed with one-third of their weight of vegetable alkali, afforded him cubic and octagonal crystals, that is, salt of Sylvius, and tartar vitriol. Phil. Trans. vol. lxvi. part ii. p. 618.

VITRIOL *of Venus* is a solution of copper in spirit of nitre, evaporated and crystallized, to gain the salt; called also *vitriol of copper*.

VITRIOL, *Liquamen*, or *Wash of*, is a name given to the ochrey matter remaining after successive evaporations of the mother of vitriol, which yields no more vitriol. Its taste is acrid and fiery, and the quantity left from a gallon of the well-impregnated liquor from the bed is about a pound. From this may be procured a white pungent salt, by subsequent evaporations. This is the saline principle of vitriol, according to the chemists, and is contained in so large a quantity, that nearly thirteen ounces of it may be separated from a pound of the liquor; the remaining liquor, after this, is what is called *liquamen vitrioli* by some chemists, but not properly. It will never coagulate into salt, but is very fiery and acrid to the taste, and extremely ponderous, not less so than oil of vitriol, nor less pungent; and is the strongest liquor any way obtained from a natural substance without distillation. This liquor being exposed to the air in a vessel not closed, will in a little time attract double its weight of water from it. All corrosive and saline liquors have somewhat of this property of imbibing moisture from the air, and weakening themselves by it; but this liquor attracts it faster and in greater quantity than any other. This liquor receives most moisture, and increases most quickly in wet weather, less so in dry; and this may have given occasion to that error so common among uninformed chemists, that several preparations of vitriol derive moisture from the moon, and have more or less of it, according to her different phases. The changes of the constitution of the air have effected what, in this case, they supposed to be done by the different phases of the moon. Phil. Trans. No. 103.

VITRIOL, *Mother of*. See VITRIOL, in *Chemistry*, supra.

VITRIOL, *Oil of*. See VITRIOLIC *Acid*, infra, and SULPHURIC *Acid*.

VITRIOLI, *Ros*. See ROS.

VITRIOL, *Saline Principle of*. See SALINE *Principle*.

VITRIOL, *Spirit of*. See SULPHURIC *Acid*.

VITRIOLATED, among *Chemists*, turned into vitriol, or having vitriol infused in it.

VITRIOLATED *Iron*. See SULPHATE *of Iron*, and IRON.

VITRIOLATED *Kali*. See SULPHATE *of Potash*.

VITRIOLATED *Magnesia*. See SULPHATE *of Magnesia*.

VITRIOLATED *Natron*. See SULPHATE *of Soda*.

VITRIOLATED *Tartar*. See TARTAR, *Vitriolated*.

VITRIOLATED *Zinc*. See *Sulphate of* ZINC.

VITRIOLIC, something that has the quality of vitriol, or that partakes of the nature of vitriol.

VITRIOLIC *Acid*. (See SULPHURIC *Acid*.) This acid, when first prepared by art, was distilled from dried sulphate of iron, or the common green vitriol, or copperas of commerce: it is still prepared in Saxony, and many other parts

of Germany, from the same substance, in the manner described under SULPHURIC *Acid*. Accordingly, when the component parts neither of the salt nor of the acid were known, it was very naturally called "oil of vitriol;" acquiring this denomination probably from its resemblance to oil in adhering to the sides of a vessel containing it, and from its passing gently, or with little noise, from one vessel to another. However, as the name tends to give erroneous ideas of the nature of the acid, which is now known to be formed only of sulphur, oxygen, and water, it ought to be expunged. On account of the inconvenience and expence attending the method of procuring this acid from sulphate of iron, and the time required for the process, the manufacturers were led to the base itself, or the sulphur; which, in conjunction with nitre, was burnt in very large globes of glass, and the product was concentrated by boiling it in retorts or other glass vessels, till the fluid was of a sufficient strength for sale. See SULPHURIC *Acid*.

Mr. Parkes informs us (Chemical Essays, vol. ii.) that the process of forming sulphuric acid by the combustion of sulphur, was first adopted in this country by Dr. Ward, well known by his analeptic pill, white drop, and some other nostrums which bore his name. Fourcroy, however, attributes this important discovery to two French chemists, Lefevre and Lemery. Dr. Ward obtained a patent for his method of preparing it, and the article which he procured was denominated, by way of distinction, "oil of vitriol made by the bell." It is needless to describe his method, though it gave him for some time a monopoly of this British manufacture: until at length chambers of lead were employed for the combustion of the sulphur and nitre, so contrived that the floor of each might be constantly covered with a sheet of water, capable of absorbing the sulphuric acid gas at the time of its formation. The introduction of this leaden apparatus served to facilitate the manufacture of this acid, and in a short time reduced the price to about a quarter of its former rate. This important improvement is ascribed by Mr. Parkes to the late Dr. Roebuck, an eminent physician of Birmingham, who, in conjunction with his partner, the late Mr. Samuel Garbett, erected, notwithstanding a violent opposition on the part of Dr. Ward, the first leaden chamber for this purpose at Birmingham, about the year 1746: and the same works are now (1815), says Mr. Parkes, in the occupation of their successors, Messrs. Alston and Armitage. The consumption, however, was at first restricted, on account of local circumstances, to Birmingham and its vicinity. The manufacturers, therefore, with a view to a more extensive demand, and to the introduction of the article produced for the purpose of bleaching in the linen manufactories of Scotland and Ireland, established, on an extensive scale, in the year 1749, works at Preston-Pans, on the eastern coast of Scotland. It is observed, however, that Dr. Roebuck was not the *sole* founder of the works at Preston-Pans, or of the great iron-works at Carron. (See CARRON.) Of Dr. Roebuck, an account of whom has been by accident omitted under his name, it will be sufficient to observe, that he was a man of very superior talents, very considerable acquirements, and very amiable manners, highly esteemed at Birmingham, where he resided, and honoured with a peculiar intimacy with the celebrated Dr. Black. He died, much regretted, on the 17th of July, 1794. After this digression, we proceed to relate, that the doctor and his three brothers, together with Mr. Garbett, and Messrs. Cadell and Sons, of Cockenzie, near Preston-Pans, were the original projectors and founders of the vast works at Carron, to the great prejudice of their respective fortunes. This circumstance, together with an unfortunate concern in a colliery at Borrowstoness, brought ruin on all the doctor's fair prospects in life. With respect to the manufacture of sulphuric acid, we observe, that for several years Messrs. Roebuck and Garbett carried on their works in England and Scotland successfully and unopposed; and, besides supplying the demands of Great Britain and Ireland, exported very large quantities of sulphuric acid to the continent. At length, in the year 1756, their prospects were beclouded by the conduct of a servant, who had the art to induce a Mr. Rhodes, of Bridgenorth, to embark in the business. This person, abandoning Mr. Rhodes, connected himself with Mr. Skey, of Bewdley, who had commenced a manufactory of sulphuric acid on a much larger scale than that at Bridgenorth; and this was the third manufactory for producing the acid by the combustion of sulphur in leaden chambers. In the year 1772, a manufactory was established at Battersea, near London; and upon the failure of this, another manufactory was instituted at Pitsworth-Moor, near Eccles, in Lancashire. Soon afterwards another work was established at Leeds; and at length similar works have been founded in various parts of England, Scotland, and Ireland: and it is said, that there are now no fewer than eight considerable manufactories of sulphuric acid at and near Birmingham. When the new method of bleaching by oxymuriatic acid was introduced, about the year 1788, the demand for sulphuric acid was very considerably augmented, so that chambers for the combustion of sulphur of much larger extent than those first constructed became necessary. Chaptal, in his "Chemistry applied to the Arts," (vol. iii.) says, that chambers about 20 feet broad, 25 long, and 15 high, seem to be the most advantageous: and it is observed, that the size of the leaden chamber in modern use, is from 20 feet in length and 12 feet in width, to 40 or 60 feet long and 16 or 18 feet wide. One manufacturer in Lancashire, however, says Mr. Parkes, has a leaden chamber of the enormous dimensions of 120 by 40 feet, and 20 feet high, thus forming a space of 96,000 cubic feet. These leaden chambers are technically called "houses," and in some districts "leaden vessels." The sulphuric acid annually consumed in these kingdoms is said to amount to upwards of 3000 tons, the greater part of which is used in a state of dilution, in which state it is consumed in large quantities by bleachers, and by calico-printers, for making what they call "sours;" and also for the purpose of dissolving iron or zinc when diluted with at least five or six times its weight of water.

The uses of sulphuric acid are very numerous. It is employed in large quantities for preparing the bleaching salt; by dyers for dissolving indigo, and for other purposes; by calico-printers for preparing sours; and by the manufacturing and the philosophical chemist, as a test for lead and barytes, and for a great variety of other purposes, some of which only can be enumerated.

The makers of the nitrous and muriatic acids are large consumers of sulphuric acid; as also are the makers of sulphate of zinc, sal ammoniac, phosphate of soda, Glauber and other salts; as well as the manufacturers of Roman vitriol, Prussian blue, and some other colours.

Sulphuric acid is likewise employed by some modern farmers in the preparation of their seed-wheat, to prevent what is called the smut; by the people who purify lemon-juice, when united to lime, in order to separate its acid in a crystalline form for the use of calico-printers and others; and by the makers of glass to convert the muriate of potash, which is one of their residuums, into sulphate of potash, and which has lately been used by them as a substitute for

ſoda. It is alſo conſumed in large quantities by the makers of tin-plate, by braſs-founders, button-makers, japanners and gilders; to all of whom this acid is become abſolutely neceſſary for the removal of the oxyd which forms on the ſurface of the iron or the copper on which they work, and which, if not removed, would prevent or impede all their operations.

Sulphuric acid is likewiſe a neceſſary article to ſome paper-makers, to fell-mongers, and to tanners;—it is uſed in conſiderable quantities by the modern hatter in the operation of felting;—and it may be remarked that refiners uſe it in the proceſs of ſtripping metals;—oil-merchants, in refining rape-oil, which it effects by carbonizing the farinaceous matter and the mucilage;—and brewers in fining what is called "gray beer:"—that the profeſſors of pharmacy as well as the chemiſts are conſtant cuſtomers for ſulphuric acid;—that it is employed in making the aſtringent and ſtomatic water of Rabel, and for other purpoſes of medicine, as well as ſurgery;—that diſtillers and rectifiers of ardent ſpirits conſume it in ſtill larger quantities;—that the makers of vinegar uſe it for the adulteration of that acid;—that many tons are annually conſumed in the preparation of liquid blacking;—and that the aeronaut, at every aſcenſion into the atmoſphere, requires many hundred weights of ſulphuric acid for the formation of the hydrogen gas, which renders the aerial machine buoyant in that ſubtile medium.

As the uſes of ſulphuric acid are become ſo various, caſes may occur of its being taken into the ſtomach by miſtake, and without immediate relief its corroſive properties would produce fatal effects. If magneſia ſhould be at hand, that earth mixed with water and ſweetened with ſugar, would be the beſt poſſible antidote to the poiſon; but in caſe this could not be immediately procured, ſoap-water, which can be furniſhed by all families, and which is one of the next beſt remedies, ſhould be drunk plentifully. Parkes, ubi ſupra.

For an account of the proceſs of manufacturing this acid, and its properties, ſee the article SULPHURIC *Acid*. For tables, exhibiting the temperatures produced by the mixture of ſulphuric acid and water, the ſpecific gravities of the acid, when diluted with different portions of water, taken at the temperature of 60°; and of the variations in the ſpecific gravity of concentrated ſulphuric acid, by change of temperature, the barometer being at 29.5 inches, we refer to Parkes's Eſſays, vol. ii.

VITRIOLIC *Acid*, in *Agriculture*, is that which is now termed or known by the name of the ſulphuric. It is noticed by the writer of the work on the Connection of Agriculture with Chemiſtry, that all acids are at preſent named from the peculiar baſes or ſubſtances of which they are formed, by the combination of pure air or oxygen; the preſence of which is neceſſary in all caſes to conſtitute an acid. This is ſtated to be the moſt powerful of all the acids, and that it diſengages or expels other acids, when in a ſtate of combination with metallic, earthy, or alkaline ſubſtances in the ſoil or otherwiſe. When concentrated, it acts in a ſimilar manner to that of alkaline ſalts, in the reſolution or deſtruction of vegetable ſubſtances, as well as thoſe of the animal kind, diſengaging from them certain gaſes, and forming therewith certain ſaponaceous and ſaline compounds. Theſe ſolutions or extracts are of a reddiſh-brown colour, ſimilar to that produced by the action of alkaline ſalts on oxygenated peat or peaty earth. The vitriolic acid may, it is ſaid, be uſed beneficially to decompoſe and bring into action the ſoluble matter accumulated in ſoils, by the combination of the phoſphoric and ſorcline or oxalic acids with calcareous matter. In this caſe, the vitriolic acid will join with the calcareous matter, and form gypſum or ſulphate of lime; while the phoſphoric and ſorcline or oxalic acids, in conſequence of their diſengagement, will combine with other matters in the ſoil, particularly with magneſia, if any be preſent, forming ſaline matters which are very ſoluble, and conducive to vegetation and the growth of plants. The buſineſs is to be accompliſhed by the uſe of ſuch ſubſtances as contain much of this ſort of acid in caſes where the other ſorts of acids prevail.

It is ſuggeſted, however, that the endleſs ſeries of proceſſes employed by nature doth not finiſh or end here; for, on a ſuppoſition that the phoſphoric and ſorcline or oxalic acids had been fully diſengaged from the calcareous matter with which they had been formerly united, and that in the ſtates of phoſphate and oxalate of potaſh, ſoda, ammonia, or magneſia, they had expended themſelves in the proceſs of vegetation; ſtill the gypſum or ſulphate of lime remaining in the ſoil would, on a renewed application of dung, urine, animal or vegetable matter, be brought from the ſtate of gypſum or ſulphate of lime, which is inſoluble, to a ſtate approaching to that of a hepar of lime, which is ſoluble; and that as the vitriolic acid and calcareous matter are contained in, and form a part of, the compounded reſiduum of vegetable matters, it may hence be inferred, that theſe matters were not generated in, but were taken up, when in a ſtate of ſolution, by the roots of plants. Thus, it is ſaid, may the good effects of gypſum or ſulphate of lime in America be accounted for without much difficulty. And to theſe beneficial effects, from the combination of inflammable ſubſtances with gypſum or ſulphate of lime, forming what is called a hepar, or liver of ſulphur, may be added the large ſhare of nouriſhment which trefoils, and plants of a certain formation of ſtem and leaf ſomewhat of that kind, receive by the hepatic air diſengaged from the hepars, when they, by the proceſs of oxygenation, are again returned to the ſtate of neutral ſalts, of which ſuch hepars had been formed by the combination of inflammable or carbonaceous matter. See OXYGENATION and SULPHATE *of Lime*.

VITRIOLIC *Minerals* are compound foſſile ſubſtances, formed of various ſtony and earthy particles, mixed with others of iron and copper, and that either ſeparately or conjunctly; ſo that, in effect, they are ores of vitriols.

The different kinds of theſe minerals are, 1. The chalcitis. 2. The miſy. 3. Sory or ruſma. 4. Melanteria. 5. Pyrites, or fire-ſtone. 6. Marcaſites. See CHALCITIS, MISY, &c.

In Europe, the only uſe made of chalcitis is as an ingredient of Venice treacle, and even here its place is generally ſupplied with common green vitriol calcined to a redneſs. The ancient Greeks uſed it externally in hæmorrhages, and collyriums for the eyes; alſo for the herpes and eryſipelas; but never ventured to give it internally.

The ancients uſed miſy for the ſame purpoſe as chalcitis, being eſteemed milder than this laſt.

At preſent it is no where put to any uſe, nor indeed does it merit it, as containing no other virtues than thoſe of green vitriol, though we are not ſure what pernicious ſubſtance it may be mixed with.

VITRIOLIC *Waters*. The countries which abound with mines of copper and iron uſually afford a great many vitriolic waters. See *Blue Vitriol*, under VITRIOL.

One of the moſt remarkable ſprings of this kind, of which we have an account, is that near Paderborn, in Germany: this is a ſort of treble ſpring, having three openings, and all three yielding very different waters. Two of theſe

openings are not more than a foot and a half diſtant from one another, and yet of ſo different qualities, that the one is limpid, blueiſh, milk-warm, and bubbling, and contains ſal ammoniac, ochre, iron, vitriol, alum, ſulphur, nitre, and orpiment; all theſe ſubſtances having been ſeparated in its analyſis. The other is cold as ice, and is turbid, whitiſh, and much heavier, and ſtronger to the taſte than the other. This holds much orpiment, with ſome ſalt, alum, nitre, ſal ammoniac, and vitriol. The firſt of theſe waters is taken by the people in the neighbourhood, againſt worms, and diſorders of the ſpleen, as alſo againſt epilepſies; the other is poiſonous to birds, all that drink of it dying in a very little time. The experiment has been tried on common hens, with the water brought from the ſprings into other places, and given them to drink.

Thoſe to which ſalt is given, after the ſwallowing of this poiſonous water, ſtruggle longer before they die by it; and vinegar is found to ſave them very often from death, after drinking largely of it; but in this caſe they are ſickly for ſeven or eight days after it, and have the pip, as the good women expreſs it.

In the diſſecting of thoſe birds which have died by drinking this water, the lungs are always found quite ſhrivelled up.

The people of the country have not been deterred by this bad effect of the water from uſing it in medicine; they take ſmall quantities of it diluted in water, to deſtroy the worms, and it performs this very well; but gives them a grievous ſickneſs while it operates.

The third ſtream, or opening, of this remarkable ſpring, is about twenty paces diſtant from the others; the water is here very clear, of a greeniſh colour, and of a ſour, but not very diſagreeable taſte. It is of a middle weight, and of middle qualities between the other two, and is evidently formed of the joining of thoſe two ſprings with ſome other freſh water in the way; for a liquor exactly reſembling this third kind may be prepared, by mixing equal quantities of the other two with a ſufficient quantity of common well-water.

There is a ſpring in Baſil diſcharging its water through the Tanners'-ſtreet, or Gerber-gaſſe, which is of a blueiſh colour, and ſomewhat turbid. This holds blue vitriol, that is copper, in the form of a ſalt, and with it bitumen and antimony; but a much larger proportion of the firſt ingredient than of either of the others. The analyſis of it ſhews, that it contains three parts copper to one of bitumen, and two of antimony. It ſerves the tanners of the place to good purpoſes, their ſkins receiving one of their preparations from this native water.

The ſame town affords ſeveral other ſprings of peculiar qualities, all owing to the veins of metalline ores with which the earth of the place abounds. The one of theſe is called Bandulph's well, and affords a water of great uſe in medicine, ſeveral being regularly and perfectly cured of hydropical diſtempers by it. And another very remarkable one contains, as is found by its analyſis, ſulphur, nitre, and ſome gold. Theſe, however, are in ſuch ſmall quantity in it, as not to prevent its being fit for the common uſes of life. It is very agreeable to the taſte, and is much eſteemed for drinking, and ſent for all over the town.

Another vitriolic water runs out of a cavern, near Gelſbach, in Alſace. It is a fattiſh and oily liquor, and is uſed by the country-people for greaſing their wheels, but it is fit for much better purpoſes. If it be boiled to the evaporation of a third part, there will remain very little water, but a fatty bituminous ſubſtance, like tar, will ſubſide to the bottom, and there will ſwim at the top a yellow, thin, and limpid liquor, very much reſembling linſeed-oil; and this, diſtilled in a ſand-heat, yields an oily and watery liquor; the firſt very good for external uſes, for burns and ſcalds; and the other a good internal medicine in conſumptions, and other diſeaſes of the lungs. Phil. Tranſ. N° 8.

Some time ago there was a water diſcovered in England, that gave, on many experiments, an appearance of containing natural and perfect vitriol. This water was found near Eglingham, in Cumberland; and being examined, by adding galls to it, it became abſolute ink, much deeper than any of the atramentous waters ever do; when one half the quantity was ſlowly evaporated, the remainder retained this quality to a higher degree than before; and on evaporating it yet farther, there concreted in it fair cryſtals of pure and genuine vitriol.

This was an appearance wholly new in England, and not eaſily accounted for, as we have no mineral, except the common pyrites, which contains vitriol; and it is very well known, that there requires a fermentation in the air, before the vitriol, contained in that ſtone, will be diſentangled from its other principles, ſo as to be capable of appearing in its own form; and as this ſtone, lying under water, can never impregnate that water with its vitriol, it did not ſeem eaſy to conceive in what manner a genuine vitriol ſhould be communicated to water, where there was no other ſubſtance which could give it. The ſuſpicions that theſe thoughts gave the gentleman who examined this water, occaſioned his making a viſit to the place where it was produced, when he found that the ſuppoſed vitriolic ſpring was no other than an old drift made for the draining of the water from ſome old wrought coal-pits; the people who had worked in theſe remembered to have ſeen great quantities of pyrites there. This drift was ſometimes dry for a conſiderable time together, and ſometimes ran in a plentiful ſtream; and there is no doubt but that, in theſe dry ſeaſons, the air acted upon the pyrites, and cauſed it to ſhoot its vitriol, which the next tide of water waſhed away, and it came off diſſolved in it, and highly impregnating it.

This proved, therefore, no better a medicinal ſpring than ſome of a like kind, deſcribed by Mr. Leigh in his "Natural Hiſtory of Lancaſhire;" and all theſe are very little better than the diſcovery of a medicated water in Old-ſtreet, from the remains of an old colour-ſhop, or Kircher's reckoning the common ſhores of Rome among the medicated ſprings of Italy.

The vitriolic ſpring which has been ſo much talked of near Haigh, in Lancaſhire, is no other than an accidental impregnation of common water, in the ſame manner: it being only the runnings of an old drift, or drain, made to carry off the water from the pits of cannel-coal; and this, like the other, as it ſometimes has water, and at other times is dry, gives time for the pyrites to let go its vitriol while dry, and then imparts it to the waters that paſs that way afterwards. Theſe are not to be accounted medicated ſprings, ſince neither natural nor continual, and ſuch may be any day made at home, by laying the common pyritæ of our clay, or coal-pits, out to moulder in the air, and then pouring water upon it, and, after a ſhort time ſtanding, taking it off again. Phil. Tranſ. N° 245. p. 380. See Ziment, and Vitriol, in *Chemiſtry*.

Voltaism

VOLTAISM. That branch of electrical ſcience which has its ſource in the chemical action between metals and different liquids, and in the proofs which eſtabliſh its identity with common electricity, the world owe principally to diſcoveries made by ſignor Volta. Its remarkable influence upon animals, which firſt brought it into notice, was firſt obſerved by Galvani. Hence it was firſt called Galvaniſm and afterwards Voltaiſm. We ſhould have treated this ſubject wholly under GALVANISM, which was then more than half completed, but the latter was not finiſhed in time to be then publiſhed. Hence the preſent article muſt rather be conſidered as a continuation of Galvaniſm, than a diſtinct treatiſe.

Galvaniſm concludes with a liſt of the different galvanic combinations, which will be terminated in this article, and the reſt will be treated in ſucceſſion. We have alſo given ſome account of all ſuch facts as have tranſpired ſince the time of the publication of the firſt part.

TABLE ſhewing the relative quantity of bubbles upon the negative wire, by immerſing a compound arc, of zinc and platina, into different ſaline ſolutions at a boiling heat, and at the common temperature.

Solution.	Effect. Hot.	Cold.	Remarks.
Muriate of ammonia	6	3	
Muriate of ſoda -	2	1	
Super-tartrate of potaſh	4	0	In this and other caſes, where the cypher is placed, it does not mean that no effect was produced, but that no bubbles could be ſeen.
Nitrate of potaſh -	½	0	In this experiment two combined arcs were uſed which juſt produced a ſenſible effect.
Phoſphate of ſoda			
Alum - -	4	2	
Sulphate of potaſh -	0	0	
Sulphate of ſoda -	0	0	
Sulphate of magneſia -	0	0	In the three laſt two combined arcs were tried, but no bubbles appeared.

The two preceding tables will give ſome idea of the relative power of different combinations of metals, and of the comparative action of different fluids.

The moſt powerful of the metallic combinations will be ſeen to be zinc with platina, gold, and ſilver; but zinc with copper is ſo little inferior, that in point of economy it will always be preferred.

Zinc with iron is, however, ſo near to zinc with copper, that iron might be uſed to great advantage where cheapneſs is deſirable.

Zinc and copper are, in the preſent ſtate of Galvaniſm, generally employed for the conſtruction of galvanic batteries. In the trough invented by Cruickſhank, the zinc and copper plates were ſoldered together in pairs, ſo as to form ſo many compound plates. Theſe plates are cemented into a wooden box, which is lined with the ſame cement, at ſuch a diſtance from each other, as to divide the trough into diſtinct cells about half wide. The order of the plates ſhould be ſuch that all the zinc plates face one way, and the copper ones the contrary.

A great improvement has been made upon the trough of Cruickſhank, by forming the cells in the trough with plates of glaſs. The plates of metal are ſoldered together by their edges, and bent at the joining, till the oppoſite ſides become parallel, and ſeparate from each other about half an inch. Each of theſe compound arcs is ſo placed in the trough with glaſs plates, that the zinc plate of each arc may be on one ſide of the glaſs, and the copper on the other, and in ſuch order, that the zinc plate of one arc, and the copper of another, may be in each of the cells. A ſecond improvement has been made upon this trough. Inſtead of a wooden trough, divided into cells with glaſs plates, the whole trough is made of earthenware, each trough conſiſting of ten cells. All the plates are fitted to a piece of wood of the length of the trough, ſo that they can be taken out or put into the trough all together. When they are taken out, the fluid is ſuffered to remain in the trough, and the plates are ſuſpended over it upon a gibbet attached to the frame in which the earthen trough is placed. An immenſe battery upon this conſtruction, conſiſting of 2000 pairs of four-inch plates, has been lately made for the Royal Inſtitution. The experiments made upon it were inconceivably brilliant. The ſpark was ſo intenſe as to ſtrike through a ſpace of ſome lines of air, and of ſuch dazzling ſplendour as to reſemble the ſun. Many ſubſtances were fuſed by the heat it produced, which had not been fuſed before, among which were the metal called fredium, and the earths zircon and alumine. Charcoal was made to evaporate, and plumbago to fuſe in vacuo. A large electrical battery was charged by inſtant contact.

Since the trial of this battery, one of immenſe ſurface has been conſtructed by J. G. Children, eſq. It conſiſted of twenty pairs of plates of copper and zinc, each plate being ſix feet ſquare, the whole exhibiting a zinc and copper ſurface equal to 720 ſquare feet. Each of the pairs of plates was united at the top by ſtrips of lead bent into an arch, and ſo as to allow the plates to be exactly parallel to each other. The cells were diſtinct and made of wood; each pair of plates entered two cells, having the wooden diviſion between them. The plates were all ſuſpended from a beam above, and counterpoiſed to admit of their being eaſily let down into the liquid in the cells. The liquid conſiſted of water with one-ſixtieth of a mixture of the ſulphuric and nitric acids, which was afterwards gradually increaſed to one-thirtieth. Leaden pipes were conveyed from the ends of the battery to an adjoining ſhade out of doors, where the experiments were made.

This battery, as a ſource of heat, ſurpaſſed any thing

ever before heard of. It melted platinum with the greateſt facility. Triſhum, which had not been before melted, was fuſed into a globule. Charcoal was kept at a white heat in chlorine gas and phoſgene gas, without any change being produced in the gas. It ignited ſix feet of platina wire. It was obſerved, that when the wire was leſs than a certain diameter, a leſs length was ignited. A view of one of the before mentioned troughs is ſhewn in *fig.* 1.

Since this plan is likely to become general, from its great advantage both in economy and convenience, we ſhall venture to ſuggeſt ſeveral improvements.

For making all the variety of galvanic experiments, it has always been a deſideratum to have a battery, the ſurface of which may be increaſed in any proportion, to a certain limit, without affecting the ſeries or number of combinations. This has not hitherto appeared practicable by any other means than that of uſing diſtinct batteries of different ſizes.

A battery on the plan above deſcribed, having looſe plates, will admit of the advantage here alluded to, without any other increaſe of expence than that of the additional plates which are meant to increaſe the ſurface at pleaſure.

The cells in the earthen trough ſhould be about an inch and a half from one dividing ſurface to the other, and capable of receiving plates of four inches ſquare. Each of the cells may occaſionally contain four plates, two of zinc and two of copper.

The form of the plates for this battery is repreſented in *fig.* 2. *Plate* I. having a wire ſtaple, *a b*, of the ſame metal with the plate. The ſtaples muſt be made accurately of the ſame ſize for all the plates. A piece of wood, *a b*, (*fig.* 3.) is made to paſs through all the ſtaples of the plates. This bearer, or ſuſpender, is divided into as many tranſverſe grooves as there are plates, of a depth capable of receiving one-half of the diameter of the wire ſtaple. In the ſame bearer are alſo two longitudinal grooves, A A, B B, about one-tenth of an inch wide and a quarter of an inch deep. A number of ſliding pieces of braſs, *a a*, are introduced into the latter grooves, equal to the number of combinations, one half of the pieces being in one groove, and the other half in the other. Theſe pieces of metal, after being placed in proper ſituations, are filed down with the tranſverſe grooves, leaving the metal above the wood, where the ſtaple of a plate is intended to touch the metal, and filing the metal away lower than the wood, where the ſtaple is not meant to be in contact.

After the plates are arranged upon the bearer, alternately copper and zinc, the pieces of ſliding metal are made to communicate with them, that the zinc plates of one cell may communicate with the copper of the ſucceeding cell, the zinc of the laſt with the copper of the next, and ſo on throughout the ſeries. The plates being all in their places and properly connected, a ſecond piece of wood, *c d*, (*fig.* 4.) is laid upon the bearer, with correſpondent grooves to fit the ſtaples. It is covered on the under ſide with woollen cloth, ſo that when it is ſcrewed to the bearer it ſerves to keep the plates ſecure, and at the ſame time preſerves the connecting parts from the fumes of the acid employed in the battery. A ſection of the bearer, ſtaples, &c. are ſeen in *fig.* 4. The whole of the apparatus complete is repreſented in *fig.* 5, as drawn out of the cell. *Fig.* 6. is an end view of the apparatus.

In this battery, the maximum of ſurface is when every cell contains two plates each of zinc and copper. When it is required to reduce the ſurface, nothing more is neceſſary than to take off the top part of the bearer, while the plates are reſting in the trough, and then drawing out the lower part. If the two end plates of each cell, one of copper and the other of zinc, be taken away throughout the whole, the bearer may be again introduced to its original ſituation. The battery will now conſiſt of the ſame ſeries and half the ſurface. If a mean quantity of ſurface be required, it is done by taking the end plates away from a part of the cells.

It appears, from an experiment detailed in Nicholſon's Journal, vol. xxvi. p. 72, that the copper ſurface may be increaſed to advantage above that of the zinc. The experiment is as follows: If an arc of copper and zinc be made to connect two glaſs cups containing dilute muriatic acid, the zinc part of the arc being in one cup and the copper in the other, and if the connection be made between the two cups, to compleat the circuit by an arc of copper wire, a quantity of bubbles will be evolved from the copper wire of the compound arc. If, however, inſtead of the copper wire the connection be made with a conical ſlip of copper, a very different effect will be obſerved, as the broad or pointed end of the ſlip may be next to the zinc wire. When the broad end is placed in the cup where the zinc wire is placed, a much greater quantity of bubbles appears upon the copper of the compound arc, than when the ſmall end is placed next to the zinc. Hence it would appear, that the copper ſurface ſhould be greater than that of the zinc. This may be very eaſily effected, by dividing the copper ſurface into ſmall grooves, the ſides of which make an angle of 60°, the ſurface will by this means be doubled. This figure might be given to the copper ſurface by means of a pair of fluted rollers. It will be obvious, that if the grooves are not very ſmall, the different parts of the copper ſurface will not be uniformly contiguous to the zinc ſurface, which is a matter of ſome importance.

Having deſcribed the moſt convenient and economical method of conſtructing a battery, we ſhall now conſider the means of exerting the galvanic energy ſo far as relates to the interpoſing fluid.

In the galvanic battery, there appear to be two ſources from which the electricity is obtained. The one is that which ariſes from the contact of the metals, and the other from the chemical action between the interpoſing fluid and the zinc ſurface. The firſt does not require even the preſence of moiſture, as is ſhewn in the electric column of De Luc. The ſecond is rendered greatly conſpicuous by introducing between the oppoſite ſurfaces any ſubſtance capable of oxydating and diſſolving the zinc.

Acids, as appears from the preceding table, are the greateſt promoters of the energy afforded by chemical action, becauſe they diſſolve the zinc after it has been oxydated by the oxygen of the water. This is more eſpecially the caſe with the ſulphuric and muriatic acids, becauſe theſe acids are not decompoſed by the zinc. The nitric acid produces a ſtill greater galvanic effect, becauſe the acid is decompoſed, and oxydates the zinc with greater facility than water. The water is alſo decompoſed when this acid is uſed. Zinc hydrogen is always evolved.

The action is always increaſed when the conducting power of the fluid is increaſed. Hence it would be proper to uſe ſome cheap ſaline ſolution with the acid, which will not be decompoſed by the ſame.

The ſaline ſolutions, alone, are very inferior to any of the acids. But from what has been obſerved, we may eaſily point out ſuch ſalts as are beſt fitted for the purpoſe. All the ſuper-ſalts, from their exceſs of acid, will anſwer this purpoſe; or ſuch ſalts as are decompoſed by zinc. All thoſe ſalts which act upon metals by forming triple ſalts, ſuch as muriate of ammonia and muriate of ſoda, are found to act very well in the galvanic battery.

It will be proper to obferve here, that the interpofed fluid does not afford a quantity of electricity proportionate to the rapidity of the oxydation, or at leaft the quantity of galvanic energy cannot be appreciated beyond a certain limit. If the quantity of the concentrated acid be much more than from $\frac{1}{20}$ to $\frac{1}{10}$ the weight of the water, the power of the battery will not be found to increafe but from another caufe, which we fhall hereafter explain; the power is much fooner exhaufted than when a fmaller dofe is ufed. The zinc is oxydated fo flowly by faline bodies, that they may be ufed in faturated folutions. Potafh, in a cauftic ftate, even when much diluted with water, might be ufed to great advantage. At the fame time that it fcarcely appears to oxydate the zinc, when a fingle pair of wires of copper and zinc are ufed, the copper wire affords as much hydrogen during the contact, as could be expected from the agency of an acid. It is, therefore, highly probable, that potafh or foda will be fubftituted for acids in galvanic experiments, as well for the fake of economy as from its being lefs offenfive to the operator. It poffeffes another advantage ftill greater, in not deftroying the zinc plates like acid folutions.

From what has been faid regarding the interpofed fluid, it will be eafy to infer that the greateft part of the galvanic energy, which is electricity excited by chemical action, depends upon the prefence of the water, and fome fubftance which can diffolve the zinc, and at the fame time give a greater conducting power to the water. The effect is not, as fir Humphrey Davy has fuppofed, produced by the oppofite electrical ftates of the elements of the compounds conftituting the fluid medium, fince the hypothefis is contradicted by experiment. If there wanted another experiment to decide, that the galvanic effect is as the chemical effect, the following would fuffice. Take two wine-glaffes, containing dilute muriatic acid, and connect them by an arc made of two wires, one of zinc and the other of platina, foldered or tied together, the zinc being in one glafs and the copper in the other. If the circuit be complicated between the glaffes by an arc of platina wire, no appearance of bubbles will be obferved upon the platina wire of the compound arc. If, however, a fmall quantity of nitric acid be poured into the glafs containing this wire, hydrogen gas will be immediately evolved from it, and at the fame time the other platina wire in the fame glafs will become oxydated. This effect is not caufed by the electrical agency of the nitric acid, which is decompofed; becaufe when copper is ufed inftead of platina, with the pure muriatic acid, the fame effect takes place. It appears, therefore, that the increafed effect would be attributed only to the oxydation of the wire of the homogeneous arc, in the glafs containing the negative wire of the compound arc.

In every galvanic procefs, from a fingle combination to an unlimited feries, no effect is obferved till the circuit is complete; and during this, a current of electricity is eftablifhed from the zinc furface of one combination to the copper of the fucceeding. While it is paffing through a metal, whatever be its length, it obeys the laws of electricity very ftrictly, but when it paffes through a humid conductor, it appears to poffefs rather anomalous properties. It is proper to obferve here, that conductors of Galvanifm are of two kinds; the one we fhall call dry conductors, and the other humid. The firft clafs comprifes all the metals, well burnt charcoal, plumbago, and the fulphurets of metals. Water appears to be effential to the fecond kind, holding in folution acids, alkalies, or neutral falts. Simple water has its conducting power increafed by the fmalleft quantity of any acid, alkali, or falt. When the conducting wires of a galvanic battery are made to terminate in a veffel of pure water the water will be obferved to be decompofed, the oxygen being given out at the pofitive wire, or that coming from the zinc fide of the battery, and the hydrogen from the negative or oppofite wire. If the fmalleft quantity of an acid, a falt, or an alkali, be added to the water, the rapidity of the decompofition will be increafed very confpicuoufly.

As it is of fome importance to know the relative conducting power of water, and its different compounds, the following apparatus has been contrived for this purpofe, reprefented in *fig.* 7. Let *e g* be a fmall cup of wood varnifhed, or, what is much better, glafs; and *z c* two wires of platina diftinctly inferted in the bottom of the cup, fo as to be water tight. A glafs tube, *o p*, filled with the fluid, is inverted in the cup to receive the gas which arifes from the wires *z c*, while the fluid defcends, and is contained in the cup. If the cup *e g* be made larger, and of an oval fhape, two glafs tubes may be inverted over each wire, and the gafes may be obtained feparately. *Fig.* 8. A B C D, is a frame fupporting one of the cups. The parts G and F are of glafs or varnifhed dry wood, cemented into the parts A B C D, which are of brafs, fo that the two fides H and I of the frame are detached. The apparatus, *fig.* 7. with four others fimilar, are to be placed in the frame, the wire *z* being inferted into one fide of the frame, and the other, *c*, refting upon the other fide. When the glafs tubes of each are filled with different fluids, the fide H is connected with one end of the battery, and that of I with the other. Since the galvanic current muft neceffarily take the beft conductor, the action will commence through that fluid having the greateft conducting power. If a thin bit of baked wood or glafs be put under the refting part *c*, in that where the action commenced, the current will be transferred to the next inferior conductor, and fo on to all the reft. By this means an accurate table, fhewing the relative conducting powers of fluids, may be eafily obtained.

Since the quantity of gas is the teft of the conducting power, fome allowance muft be made when the muriates are the fubject of experiment. Almoft all the oxygen gas difappears in converting the muriatic into oxymuriatic acid. In a fimilar way the hydrogen does not appear when certain metallic folutions are employed, fince it combines with the oxygen of the metallic oxyd, and the metal is reduced. When the battery is in full power, and of great extent, the relative conducting power of the fluids may be expreffed by the time required for the afcending gas to difplace the liquid in the glafs tube. In all thofe experiments where the elements of bodies are transferred to different fides, the transfer takes place through any of the moift conductors, but not through any of the dry ones. No transfer can therefore be made through folid bodies, except the body be permeable to moifture. Sir Humphrey Davy, in his experiments, made ufe of the fibrous afbeftus moiftened with water. Where the fluids are required to be ftrictly feparate, bladder anfwers very well as a feparating medium. Animal and vegetable fubftances, however, abound with fo many elements, that in nice experiments they would be objectionable. A veffel divided into a proper number of cells of earthenware, in the ftate of bifcuit, would be beft calculated for thefe experiments. This veffel fhould be made of pure filex and pure alumina. Should it ever become an object of manufacture to feparate acids and alkalies from neutral falts, a veffel of wood, with a feparation in the middle, of unglazed earthenware, would anfwer very well.

We fhall here mention fome curious facts connected with the interpofition of metals, in different conducting media.

When the wires, coming from the two ends of a galvanic

battery, are brought into separate vessels containing any fluid which is a conductor. If a wire of platina, in the form of an arc, connect the two glasses together, that end of the connecting arc in the positive glass will afford hydrogen gas, while that in the negative glass will furnish oxygen gas; or, if we take all the four ends of the wires in the circuit, the positive wire from the battery will give oxygen, and that opposite to it, in the same glass, hydrogen. In the other glass, the negative wire will afford hydrogen, and the opposite wire oxygen, so that the water appears to be decomposed in each glass, since oxygen and hydrogen are furnished separately by each glass. If a number of glasses be arranged similarly, having connecting arcs of platina, and if the wires of the battery be introduced in the extreme glasses, all the ends of the wires will alternately furnish oxygen and hydrogen. No theory yet brought forward will satisfactorily account for these phenomena. Sir Humphrey Davy would assert, that each of the wires from the battery induced an opposite state of electricity in the wires opposed to them; and that in consequence the one attracted oxygen and the other hydrogen. Another theorist might hold that the electricity, which enters the first glass from the positive side, decomposes the water, and combining with the hydrogen, sets the oxygen free. The electricity and the hydrogen pass through the fluid to the opposite wire, when the electricity deserts the hydrogen, and passing through the platina arc, decomposes the water in the second glass. The oxygen is again evolved, and the hydrogen carried to the next wire, and so on through the remainder of the glasses.

A very curious experiment of the above kind rather tends to confirm the latter, than the former hypothesis. We, however, give these facts to the common stock, for the advantage of other labourers in this field of inquiry; strongly convinced that every hypothesis yet advanced falls very short of explaining all the phenomena of Galvanism.

Let the wires of a galvanic battery be made to terminate in a flat-bottomed vessel, containing pure water, about an inch and a half from each other; and if now another wire, of an inch in length, be laid longitudinally between them, but not to touch them, each end of the intermediate wire, if of gold or platina, will afford gas. That end opposite the negative wire will give oxygen, and the other end of the same will furnish hydrogen; and if any number of bits of wire be placed between the principal wires, at the same time they do not touch each other, oxygen and hydrogen will be alternately furnished by the ends of the wires. When the principal wires are brought nearer together, and a platina wire placed transversely between them, one side of the intermediate wire will furnish oxygen, and the other hydrogen. This fact is put in a more striking point of view, by placing a plate of platina in a vessel of water edgeways, and bringing the wires of the battery opposite to each other, and perpendicular to the sides of the plate. If the battery employed consist of 50 plates three inches square, a circular spot will be observed on each side the plate, opposite the wires. This appearance is caused by the evolution of gas from those parts of the plate only.

It is singular, that in all the experiments where the connecting wire was immersed in the water, if any substance, capable of increasing the conducting power of the water, be very gradually added to it, the gases given out by the intermediate wire will diminish, till they entirely cease to be produced. The wire which was transversely placed sooner ceased to afford gas, than when it was in a longitudinal position; and the effect sooner ceased with the wire than with the plate: and in different plates, the continuance was as the size of the plate.

If the plate, however, be cut so as to divide the vessel into two portions, and the edges so completely cemented to the sides of the vessel that no liquid communication exists between the two portions, each side of the plate will furnish as much gas as the wires, whatever may be the conducting power of the fluid. If the power, which induces the plate or immersed wires to give out gas, depended upon the induction of the opposite wires, why is it not as great before the fluid is divided as afterwards? and why is it the same when pure water is used, whether the intermediate wire be immersed in the water, or is made to connect two portions of water together? These are facts which, in the present state of knowledge, do not admit of easy solution. They, however, shew us the necessity of having the cells of our galvanic batteries perfectly distinct from each other. It appears pretty clear, that that which conducts the oxygen or the hydrogen, or perhaps both, passes with greater facility through a good moist conductor than through a metal.

Decomposition of Bodies in general.—The decomposition of water and of metallic oxyds was known to Cruickshank, the history of whose experiments we have already given; and in a very early stage of galvanic progress, it was observed that the alkali was separated from muriate of soda in the galvanic battery. In subjecting muriate of soda to the galvanic power in a glass tube, it has also been observed that oxymuriatic acid was produced. The subject of the decomposition of salts, however, has been clearly made out, and established on true principles, by sir Humphrey Davy, whose experiments have been detailed under GALVANISM. The chemical agency of bodies, arising from their relative electric states, is no doubt the cause of the decompositions of salts, and of all other bodies to a certain extent; although there are many decompositions, particularly the metallic oxyds and water, which are to be attributed to some other cause much more active and expeditious. We shall here venture to draw a line of distinction between the decomposition effected by the electrical intensity arising from the contact of the bodies, and that produced by the electricity, and the hydrogen developed by the chemical agency of the oxydable metal, and the oxydating fluid.

If we take a single combination, for instance, a zinc wire connected with a platina wire, the electrical intensity arising from contact is so exceeding small, that it could hardly be appreciated by the acid of the condenser. If this combination be immersed in water, no galvanic appearance takes place, however near the immersed ends be brought to each other. If, however, we add to the water about one-tenth its weight of muriatic acid, an immense quantity of hydrogen immediately appears upon the platina wire, and continues to be evolved so long as the contact is formed, till the acid is expended. The electrical intensity, however, is the same with the water as with the dilute acid; yet the quantity of hydrogen upon the platina wire, when the acid was used, which can be attributed only to galvanism of chemical action, is much more than could be obtained by the most powerful electric machine. It can readily be admitted, from experiments in which Dr. Wollaston decomposed water by the electric machine, and from the electric effects of Deluc's column, that some water would be decomposed by the single combination, independently of the chemical action; but the difference is so glaring as to produce the strongest conviction, that the decomposition of water and the transmission of hydrogen are not dependent on the mere electric states of the wires. That the hydrogen is

transmitted from the zinc to platina, during the chemical action, many experiments seem to prove; and that the hydrogen so transmitted, by its chemical agency, and in its nascent state, is capable of effecting many decompositions, which, under other circumstances, would be impossible. In the single combination above alluded to, if the dilute acid be separated from a solution of acetate of lead, or sulphate of copper, by a piece of bladder, the zinc being immersed into the acid part, and the platina into the metallic solution, no hydrogen will be afforded by the platina, but the metal becomes reduced in proportion to the quantity of hydrogen which has disappeared: yet no perceptible quantity of this effect can be attributed to the electricity of contact, but to the mere chemical agency of hydrogen in its nascent state. Hence we are inclined to think, that the decompositions by the galvanic battery arise from two causes. Water principally owes its decomposition to the chemical action, and the agency of the electricity upon the hydrogen. Metallic oxyds are principally decomposed by the presence of the nascent hydrogen, so collected and transmitted by the electricity. The decomposition of saline bodies, however, is to be attributed alone to the electrical attraction produced by the contact of the bodies employed, which can be made so great as to overcome the chemical attraction of the bodies decomposed. Of the latter of these powers of decomposition we have given some account, in detailing the ingenious experiments of sir Humphrey Davy; of the two former means of decomposition we shall say something in a practical point of view.

Many very anomalous facts were known in chemistry long previous to the discovery of Galvanism. All those chemical phenomena, under which the appearance called arborescence was observed, were inexplicable, till it was shewn from some experiments, published in Nicholson's Journal, vol. xv. p. 94, that Galvanism is the cause of these singular phenomena. In the experiment where lead is so beautifully precipitated, by suspending a piece of zinc in a solution of acetate of lead, the zinc first reduces a small portion of lead, which, with the zinc, forms a galvanic combination. The lead, if no solution of lead were present, would now give out hydrogen gas; but the hydrogen, instead of appearing in that form, combines with the oxygen of the oxyd, and the metallic lead is formed at the same point. Hence the lead appears to grow from the last point formed, which gives the appearance of vegetation. That this effect does not depend upon the presence of zinc, may be proved by the following experiment. Tie on one end of a glass tube, about half an inch wide, a piece of bladder, so that it may hold water, and fill it with a solution of acetate of lead. Into the other end insert a cork loosely, and through the cork let a platina wire pass within about half an inch of the bladder. Into a wine-glass put some dilute muriatic acid, in which place a zinc wire. When the tube with the bladder is immersed in the wine-glass, if that part of the zinc wire without the glass be brought into contact with that part of the platina wire without the tube, beautiful crystals of metallic lead will soon appear upon the platina wire. If the acetate of lead be removed, and a dilute acid be put in its place, bubbles of hydrogen will appear upon the platina wire.

Another experiment, similar to that of the lead-tree, and equally anomalous, has been long known in chemistry. If a plate of glass be smeared over with a solution of nitrate of silver, and a brass pin or a piece of zinc wire be laid in the middle of the plate, beautiful ramifications of silver will soon appear as if growing out of the pin, very much resembling vegetation. By observing the process with a magnifying glass, each branch of this arborescence may be seen to grow from the end or side of another; which proves that the silver forming the vegetative appearance is not reduced by the oxydable metal laid on the plate, but by something at the successive points of the silver branches. With a view to ascertain this fact, one half of the plate should be smeared with nitrate of silver, and the other half with dilute muriatic acid. If a piece of zinc wire be tied to a piece of platina wire, and the compound wire so bent that the zinc may touch the dilute acid, and the platina the nitrate of silver, the ramifications of silver will soon appear upon the platina wire. That the silver is reduced by the hydrogen carried in the galvanic current, is probable from varying the experiment as follows: If, instead of smearing the plate with nitrate of silver, the whole be covered with dilute acid, and the same compound arc be laid upon it, the platina will give out bubbles of hydrogen. In the common way of making this experiment with the pin, as well as the variation above stated, it appears that the process is kept up by the galvanic current, which furnishes the hydrogen. The pin first reduces a small portion of silver, which forms a galvanic combination with the pin. The hydrogen which, but for the presence of the remaining nitrate of silver, would appear in the gaseous form, is employed in depriving the silver of its oxygen. With the compound arc, the zinc does not require to touch the nitrate of silver, because the platina with zinc is already a galvanic combination. The theory of whitening common pins can be explained only on this principle. The tin, in a small proportion, is dissolved in the tartrate of potash; pieces of metallic tin, with the pins, are also present. The two latter form the galvanic combination, and a portion of tin is reduced from the solution upon the pins, to which they owe their whiteness. We may generally conclude, that in all instances where one metal becomes the precipitant of another, the precipitation is much facilitated by the agency of the galvanic combination, formed between the precipitating and the precipitated metals, and the consequent presence of hydrogen. If a piece of zinc be introduced into a solution of sulphate of copper, the zinc in the first instance becomes covered with copper, and the effect appears to stop. If, however, a very small excess of sulphuric acid be added, the process will go on with such rapidity, that the copper becomes precipitated in a very little time. By minutely observing the process, the copper will be seen to be reduced upon that already produced, which is a proof that it is not done by the mere agency of the zinc.

It appears very evident, that when a galvanic combination of zinc with any lesser oxydable metal is placed in a dilute acid, that a much larger quantity of hydrogen will be evolved from the lesser oxydable wire, than could possibly be produced by any electrical intensity generated by the contact of the bodies employed; but that independent of this, there is an immense quantity of electricity generated during the chemical action, by which the hydrogen is transported from the greater oxydable surface to the lesser one. If the quantity of hydrogen produced depended upon the attraction of the wires for the elements of the water, this power would depend upon the electrical intensity alone, and of course upon the series in the galvanic battery, whatever might be its surface; but it is found that the power of Galvanism to decompose water is much increased by an increase of surface only.

Galvanism as a Source of Heat.—When the wires coming from the ends of a galvanic battery of considerable surface

are brought into contact, a brilliant ſpark is produced, and the wires ſtick together with conſiderable force, as if they were welded, or united by fuſion. If the parts in contact be held with the fingers, a conſiderable heat will be perceived, which will be greater as the battery is more powerful, and inverſely as the thickneſs of the wires.

Small wires ſeem to affect the electric fluid in a manner ſimilar to that in which light is affected by a convex lens, or a concave mirror, by concentrating and compelling a large quantity of electricity to paſs through a ſmall channel. This appears to be the caſe with common electricity, as well as galvaniſm, ſince by diſcharging the electrical battery through very ſmall wires, the metals become fuſed and oxydated.

On the galvanic battery this experiment ſhould be made as follows: at each end of the battery ſhould be placed a rod of metal, with a clean ball at the top of each. Between the two balls muſt be ſtretched a piece of very ſmall wire, not exceeding $\frac{1}{100}$th of an inch in diameter, while the circuit is interrupted in ſome other part of the battery. As ſoon as the wire is fixed, the circuit muſt be completed where it was broken, and the current will inſtantly be determined through the ſmall wire, which will in conſequence become ignited.

It was diſcovered by Dr. Wollaſton, that, in the ignition of wire by the voltaic battery, there was one certain diameter of the wire, in which the length ignited was the greateſt, above or below which the length was leſs. This does not ariſe from more heat being ſent through the wire in which the greateſt length was ignited, but from the ratio of the ſurface of the very ſmall wire being ſo much greater to its ſolidity than in thicker wire, by which a greater proportion of heat is carried off by radiation; but when the diameter is beyond a certain extent, then a leſs length is ignited, from the heat being leſs concentrated.

It has alſo been found, that very different lengths of wire are heated of different metals when their diameters are equal. This appears to take place from the relative conductive powers of the different metals for electricity, which appears to be as their conducting powers for heat. Platina, being the worſt conductor, has a greater length heated; and ſilver, which is known to be a good conductor, has a leſs length heated.

If the battery be very powerful, it will be fuſed and oxydated. When a connection is formed between the two ends of the battery, by means of the very thin foils of metals, ſuch as leaf-gold, the metals undergo brilliant combuſtion, exhibiting different coloured flames. Charcoal and plumbago, preſented by ſharp angles, are ſimilarly deflagrated. If the ends of the two wires coming from the battery be made to touch each ſide of a ſmall globule of mercury, the latter will inflame with a bright flaſh. This heat, furniſhed in the galvanic current, is alſo very apparent while it is paſſing through moiſt conductors. Different fluids ſubjected to decompoſition in the circuit, in glaſs tubes, become conſiderably heated, and this will be found the caſe, as the diameter of the tube is leſs.

Sir H. Davy attributes this heat to the decompoſition, which muſt ſtrike any one as being an error. Heat we always find to be evolved during combination; the very reverſe of which ought to take place during decompoſition.

Action of Galvaniſm upon Animals. — All animal ſubſtances, either dead or living, if not deprived of their moiſture, are tolerably humid conductors of Galvaniſm. In the living ſubject, independent of its conducting power, it has the property of being affected in a peculiar manner. All thoſe animals which poſſeſs excitability are affected by Galvaniſm as they would be affected by any other violent ſtimulus; and if the excitable part be at all muſcular, the fibres are vigorouſly contracted. This cauſes, in a living and conſcious animal, a ſenſation not unlike an electric ſhock. The ſhock is more like that of common electricity, as the plates of the battery are ſmaller and more numerous. When the plates are of very large ſurface, a ſort of vibratory motion is felt through the part attended with a ſenſation of heat; and this, in a powerful battery, is felt ſo long as the connection is kept up. The beſt mode of taking the ſhock is firſt to moiſten the hands, or the part where the effect is to be applied; graſp in each hand a piece of metal, ſuch as two ſpoons, and touch each end of the battery with the other ends of the ſpoons at the ſame time. If it is intended to be applied to any other part, let two plates, of about two inches in diameter, be each attached to the wires coming from the battery, and let the plates be applied to ſome two parts: if the effect be too ſevere, let ſome inferior conductor be placed between the plate and the ſkin.

Sir H. Davy found, that when an animal ſubſtance was placed in the circuit of a galvanic battery, the different compounds contained in it were decompoſed. This was more eſpecially the caſe with the ſaline bodies contained in the animal fluids; the acids of the ſalts were found on the poſitive ſide of the battery, and the baſes of the ſalts on the negative. Should it be aſcertained that any redundancy of ſaline matter is the cauſe of diſeaſe, Galvaniſm might be employed with great ſucceſs in ſeparating thoſe bodies from the ſyſtem.

Dr. Wollaſton has given ſome hints in Nicholſon's Journal, from which it appears probable that the power of the glands in ſecreting different fluids is dependent upon the electrical ſtate of the glands; by which they are induced to attract all bodies in a contrary ſtate to themſelves. The opinion of this ingenious gentleman has been ſtrongly corroborated by ſome experiments made by Meſſrs. Home and Brandt. Phil. Tranſ.

Theſe, however, are ſpeculations on which we cannot at preſent place ſtrict reliance. The ſame conjecture which is applied to ſecretion may be applied to the oxygenation, or rather the decarbonization of the blood in the lungs; ſince the carbon appears to be transferred through the membranes between the pulmonary arteries and the interior of the lungs. The ſame theory may be alſo applied to account for the change of the colour of the blood between the fœtus and the mother. Muſcular excitability may perhaps ariſe from a certain electric ſtate of the muſcular fibre cauſed and kept up by the arterial blood; and if we may be allowed to carry the conjecture ſtill further, muſcular motion may perhaps be cauſed by the relative electric ſtates of the muſcles, and the brain and nerves.

Waggon

WAGGON, in *Agriculture* and *Rural Economy*, a kind of vehicle or carriage in common ufe. There are divers forms of waggons, accommodated to the divers ufes they are intended for. The common waggon confifts of the *fhafts*, or *rads*, which are the two pieces the hind horfe bears up; the *welds*; the *flotes*, which are the crofs pieces that hold the fhafts together; the *bolfter*, being that part on which the fore-wheels and axle-tree turn, in wheeling the waggon acrofs the road; the *cheft*, or body of the waggon, having the ftaves or rails fixed thereon; the *bales*, or hoops, which compofe the top; the *tilt*, the cloth thrown over the hoops; befides the *wheels*, *axle-tree*, &c.

Waggons are too frequently conftructed without that proper attention to the nature of the roads, or the forts of articles which are to be conveyed by them, which is neceffary, being in general heavy, clumfy, and inconvenient conveyances. There is, however, a waggon of this kind, which is much employed in the county of Berks, that is formed and built on a more fimple and convenient principle than thofe commonly met with in moft other fouthern parts of the country, and which has not either the height or weight of them, while it poffeffes fufficient ftrength, and is eafy in the draught. The writer of the firft account of the agriculture of that diftrict has, however, fuggefted an improvement to be made in it, which is that of leaving the fpace fufficiently deep in the body or bed for the fore-wheels to lock round in the fhorteft poffible curve, as in the prefent manner of its conftruction, a great deal of time is neceffarily loft in the turning at the ends of the fwaths and plats in carrying hay or corn, as well as on fome other occafions, as in this way the inconvenience may be removed without doing the fmalleft injury, it is faid, to the fymmetry or ftrength of the carriage or waggon.

In the corrected report on the agriculture of that diftrict, which has been more lately drawn up, it is however noticed, that fome farmers of the foreft part remark on the above, that the waggon would be much weakened by the propofed alteration; and add, that an improvement has lately been made on the waggons of this county, which is found to anfwer the purpofe of the above fuggefted alteration, which is the locking chain, as it is called; which is a chain from the pillar of the waggon, to about fix inches before the middle bed ftay, which is made of fuch a length, as effectually to prevent the waggon catching on the lock. Where the beds of the waggons are ftraight, as is common, it is faid, in the fouthern parts of the fame county, the improvement firft propofed would probably, it is thought, be ufeful; but that in the vale and middle parts, the beds are otherwife conftructed, and fcarcely admit of alteration for the better.

A waggon, too, which is peculiar to Cornwall, is faid to be light and elegant, being ufed there for carrying corn and hay in harveft time, and faggot-wood, as well as for many other purpofes. The body is open, which with a lade of five bars fixed before and behind gives it great length, while an arch put over the hind wheels gives it breadth; the forewheels turn clear under the body, fo that it can fweep round in a very narrow compafs; the load is fecured by two ropes tightened by a fort of winch fixed behind the waggon; it carries about three hundred fheaves of corn at a time. A tongue tree, fometimes called a middle tree, or fhafts, are

occasionally fixed to the axle of the fore wheels, according as it is intended to be drawn by an ox or a horse-team. This light waggon is thought to be deserving of a place on almost every large farm in the kingdom.

But the writer of the rural economies of the different counties of the kingdom, who has attended much to the subject, thinks that those which are employed in the county of Gloucester are to be preferred to any others in the country; as by means of crooked side rails, bending archwise over the hind wheels, the bodies or frames of them are kept low, without the diameter of the wheels being much lessened. The bodies are likewise, it is said, made wide in proportion to their shallowness, and the wheels run six inches wider than those of most other waggons, whereby advantages in carrying top-loads are, it is said, evidently obtained. Mr. Rudge, too, in his account of the agriculture of the same district, has remarked that, in many parts of it, waggons are the principal carriages employed in getting in the hay and corn, and are either full-bedded or with three-quarter beds. That the former have the advantage of a greater length of bed, but are not so convenient for turning; and that the latter, though diminished in size, have the convenience of locking the fore wheels, and turning in almost as narrow a compass as a chaise, in consequence of the bed being hollowed out on each side near the middle, to admit the exterior part, or felloes of the fore wheels. Both these sorts of waggons are capable of carrying nearly, it is said, the same weight, though the former, as being deeper in the bed, is somewhat better adapted, it is thought, for the carriage of heavy articles, such as bags of corn, and other such materials. For the purpose of carrying hay and straw, or of harvesting, their length and width are, it is said, increased by light ladders before and behind, and of similar contrivances, called "rathes," the whole length of the sides. The ladders are put on and taken off at pleasure in both kinds, but the side additions are generally fixed; except in the straight-headed sort, which are in use, it is said, on the western side of the Severn, in this county; in these they are made removeable, so as to leave the bed quite naked.

Another sort of waggon, which partakes, in some measure, of the properties of both the waggon and cart, on which account it has been appropriately denominated the *hermaphrodite*, is, it is said, frequently made use of in the county of Norfolk, when the pair of fore wheels and shafts are occasionally attached to a common cart by a pole connected with the axle, to which are added the ladders. This is, it is said, a light, cheap, and convenient sort of waggon, which is capable of carrying nearly as much hay or straw as that of the Berkshire.

As it has been observed, that from its having been long a complaint among large farmers, and others, whose business requires the constant use of carts, and only the occasional use of waggons, that the waggon, however well preserved by a shed or other such building, is daily decaying and getting worse while out of use, particularly the iron work of it, which is shortly destroyed by rust; and that, in like manner too, with those whose concerns require the almost constant use of waggons, and but the occasional use of carts; the latter, while unemployed, bear a very considerable proportion to the wear and tear of carts which are in constant use: these circumstances and effects have led and induced a Mr. Rood to devise and bring to perfection, at a very considerable expence, a contrivance of this particular kind, by which the same carriage may, in a few minutes, be made by the carter into two complete tip carts of the common dimensions, and applicable to all the uses of carts in general, or into one waggon, so complete, that a narrow inspection is, it is said, necessary to distinguish it from a common waggon. And that there is no complication of parts in this waggon, the whole being so contrived, that none of its parts are ever out of use, consequently not liable to be mislaid or lost. The carts, too, when it is formed into them, have a contrivance by which to render them more safe and easy to the horse in going down a hill, and have moveable side ladders, which will, it is said, be found of great use in carrying corn, bark, and other such materials. It is noticed, that it may be constructed by the wheelwrights of any county or district with perfect ease and facility, and that its shape and particular dimensions are capable of being suited to the wishes of the owner, or to the local fashion of the neighbourhood in which he lives. That the result of considerable experience and enquiries enables the inventor to state that it may be completed, in any county or district, for about five pounds more than the cost of two common carts. It is admitted, however, that it is somewhat more clumsy than a common waggon.

It is united and held together by four strong pins, which are to be removed when it is disunited and used in the separated state.

A representation of it may be seen in the second volume of the "General Dictionary of Agriculture and Husbandry."

In the county of Norfolk, Mr. Douton, of Brandon, according to the writer of the corrected report on the agriculture of that district, has found a considerable saving by the use of light caravan waggons for two horses abreast, with which he carries, it is said, a chaldron and half of coals, and other loads in proportion; and that, it is thought by him, every man, who reduces the teams of any county or district, will be sure to do this until he arrives at perfection in a one-horse carriage.

In most counties, however, still much too heavy carriages of the waggon kind are in use for the business of farming as well as road purposes. In Kent, the carriages of this sort employed in conveying the corn to market and other places are large, and called hutches, being drawn by four horses; and generally loaded with not more than from seven to twelve quarters of corn, according to its weight, and the distance it is to be carried. They are thirteen feet long, are made crooked at the sides, the width cannot however be positively ascertained; but they are generally three feet wide before, and four behind at the bottom; and about six or eight inches wider at the top, being twenty inches deep: they are boarded at the sides and ends close enough to carry sand. If made with wooden axle-trees, they cost, it is said, about twenty guineas: if with iron, twenty-five. Such waggons are, however, quite unfit for many farm uses.

In Staffordshire, it has been observed by Mr. Pitt, that the reduction of the weight of waggons, in most cases, but particularly to those who are common carriers, is highly beneficial, being a gain of not less than fifty pounds a year by each team constantly employed on the road; and that if it be made with good materials a light waggon will last as long as a heavy one. The cost of a narrow-wheeled waggon there is twenty-six pounds; six inch, thirty-six; the axletree is most commonly of wood.

The author of the "Present State of Agriculture and Husbandry in Great Britain," remarks that waggons are chiefly used in getting in the hay and corn harvests, carrying the hay and grain to market, and bringing manure and coals from a distance. That they are generally drawn by the whole team on the farm, where one only is kept, whatever number of animals it may consist of, and that two men

and a boy are moſtly neceſſary to attend them. That in performing diſtant carriages, when the roads are level and ſubſtantially made, and the waggons at all times fully loaded, one of them may probably be as advantageouſly uſed as two or more carts of leſs dimenſions. But that where the labour is required to be performed with expedition, as in the hay and corn harveſts, theſe unwieldy machines and contrivances are without doubt ill calculated for the purpoſe; and that on every occaſion, when they return half or a third loaded, it is evident the farmer ſuſtains a conſiderable loſs. Inſtances have occurred to the writer, it is ſaid, in more than one open-field pariſh in this part of the country, where a waggon, with three or four perſons and as many horſes, has been diſpatched to collect and carry home ſcattered parcels of hay from the ends of ridges, which, after going over a great extent of the pariſh or diſtrict, returned only partly loaded. Conſidering the very high rate of labour, and the ſhamefully extravagant manner in which, in hay or corn harveſt, labourers and farm ſervants are maintained in this part of the kingdom, it is ſurpriſing, it is thought, that every farmer does not exert himſelf to deviſe and find out means by which he may perform his work with greater expedition, and at leſs expence. There are ſome, however, who think that this ſort of carriage or conveyance, however well formed and conſtructed, from its neceſſary great weight and unwieldineſs, as well as its expence, is moſtly far from being advantageous to the intereſt of the farmer; as while it is highly deſtructive to the roads, it requires great power to draw it, which muſt be procured at much coſt, without affording an adequate compenſation in the increaſed quantity of materials which it carries.

Waggons unqueſtionably require much more power in the draught in proportion than carts, which is certainly a material objection againſt them, though they are capable of conveying a much greater load; but, beſides, they are far from being ſo handy and convenient for many ſorts of farm-work; and ſome too are of opinion that more buſineſs may be done in any particular ſpace of time, with the ſame number of horſes, by carts than by waggons, in the general run of huſbandry work, eſpecially where the diſtance is ſmall between the places of loading and unloading. That where waggons are uſed for farm-work, they ſhould be made wide and low, as the moſt ſuitable in different intentions. Manures may be carried in theſe ſorts of waggons almoſt as well, it is ſuppoſed, as in carts. Broad wheels are improper for paſſing and repaſſing upon tillage lands; as if in fallow they preſs the land too much, making it ſo hard as to prevent its being ploughed until wet comes; but on graſs-land, wheels of the broad kind are proper and ſuitable for all purpoſes. In Berkſhire, Mr. Loveden is ſaid to put narrow fore-wheels to his waggons, and broad ones behind, in order to prevent injury to tender graſs-land. The hind-wheels in this way roll over the tracks made by the fore, and remove the miſchief they have done. The method is thought to be excellent, and of very eaſy application.

On the whole, waggons are probably the moſt proper and ſuitable ſort of conveyances for different kinds of heavy loads that are to be carried to a diſtance; but that for home uſes, eſpecially field and other work, which requires to be executed in a ſpeedy manner, carts with proper ſhelvings and other conveniences are to be preferred, as more ready and economical. See CART.

In the work of reducing the weight of waggons for farm uſes, as well as for road and other purpoſes, it ſhould always be done with much care and attention, in order that it may be taken from ſuch parts of them as have not great force of draught or preſſure upon them, and that thoſe parts which are much expoſed in theſe ways may be left ſufficiently ſtrong. In the weight and ſhape of the wheels ſome reduction and alteration may likewiſe take place, as may be ſeen in ſpeaking of wheels. See WHEEL.

WAGGON, in the *Military Economy*, is a four-wheeled carriage, drawn by four horſes, and applied to various purpoſes.

WAGGON, *Ammunition*, in *Military Language*, is a waggon uſed in carrying all kinds of ſtores, and alſo bread; for which purpoſe it is lined on the inſide with baſket-work.

WAGGON-*Maſter-General* is he who has the ordering and marching of the baggage of the army. On a day of march he meets the baggage at the place appointed in the orders, and marſhals it according to the rank of the brigade or regiment each waggon belongs to, which is ſometimes in one column, ſometimes in two; ſometimes after the artillery; and ſometimes the baggage of each column follows their reſpective column.

WAGGON-*Way*, the ſame with RAIL-*Way*; which ſee.

Wales

WALES, a large diftrict or portion of Great Britain, fituated at the north-weftern extremity of the ifland, and bounded on the north and weft by the Irifh fea, on the fouth and fouth-eaft by the Briftol channel, and limited on the eaft by the Englifh counties of Monmouth, Hereford, Salop, and Chefter. The length from north to fouth is, on an average, 150 miles; and the width from eaft to weft 65 miles. This area comprifes about 8125 fquare miles, or 5,206,900 acres of land: of which, it appears, by the reports to the board of agriculture, 900,000 acres are arable, and 2,500,000 under pafturage; leaving 1,700,000 acres in a ftate of wafte, of which 700,000 acres are reported as capable of being brought into cultivation. Wales was formerly of greater extent, having for its boundaries the rivers Severn and Dee, as natural lines of demarcation. The ancient dimenfions were, however, at various periods, contracted, by fevering from it portions of the feveral counties, fituated weftward of thofe rivers; and taking out of it the whole county of Monmouth. The limits of the various diftricts of Wales, with the above exception, and their names, have been retained from a very remote period to the prefent time, independently of the modern arrangement of them into fhires, as impofed by the Englifh government. The divifion made in the time of Llewelyn ap Gruffydh, the laft prince of North Wales, was into the three provinces of Aberfraw, Mathraval, and Dinevwr. In the diftribution of thefe into cantrefs or hundreds, Aberfraw comprifed fifteen, which were again fubdivided into thirty-eight comots, or fmaller diftricts; Mathraval, fourteen cantrefs, fubdivided into fourteen comots; and Dinevwr, twenty-four, further divided into feventy-eight comots. Nearly fimilar to this, is the prefent civil divifion of the principality into twelve counties, fix included in North Wales; *viz.* Anglefea, Caernarvon, Denbigh, Flint, Montgomery, and Merioneth; and fix in South Wales, *viz.* Cardigan, Radnor, Brecknock, Glamorgan, Caermarthen, and Pembroke. The centurial divifions remain nearly the fame as in Llewelyn's time. The whole contains 58 market-towns, and 751 parifhes; and according to the enumeration made under the population act of 1811, the number of houfes amounted to 123,512, inhabited by 611,788 perfons; *viz.* 291,633 males, and 320,155 females: 36,044 families were returned as employed in trade, manufactures, or handicraft; and 72,846 in agriculture: and the average fcale of mortality, according to regiftered burials, for a period of ten years, appears to have been in the proportion of 1 to 60 of the exifting population. For the adminiftration of juftice, Wales is divided into four cir-

cuits, *viz.* the Chefter circuit, including the counties of Chefter, Flint, Denbigh, and Montgomery: the northern circuit, for thofe of Anglefea, Caernarvon, and Merioneth: the fouth-eaftern, for thofe of Radnor, Brecknock, and Glamorgan: and the fouth-weftern, comprifing the three fhires of Cardigan, Caermarthen, and Pembroke. By a ftatute, paffed in the reign of Elizabeth, the king was empowered to appoint two perfons learned in the law to be judges in each of the Welfh circuits, which before had but one juftice. And by another ftatute of George II., it was enacted, that where the kingdom of England is mentioned in any act of parliament, the fame fhall be underftood as comprehending the dominion of Wales, and the town of Berwick-upon-Tweed. Wales fends twenty-four members to the Britifh fenate, one knight for each fhire, and one burgefs for each county-town, except that of Merioneth; in lieu of which, two towns in Pembrokefhire return a member each, *viz.* Pembroke and Haverford-weft. The eldeft fon of the kings of England has, ever fince the time of Edward I., been invefted with the title of prince of Wales: and feveral branches of the peerage derive their titles from various places in the principality.

Ancient Hiftory, Roman Stations, and Roads.—Cambria, the ancient name of this portion of the ifland, is deduced by hiftorians from the original inhabitants having been a tribe of the Celtæ, or Gauls, known under the denomination of *Cimbri*, or *Cymri;* and the Romans called the country inhabited by fuch people Cambria. Wales appears to have been the acknowledged name of this region in the poetry of a Welfh bard, fo early as the fixth century. The derivation of the Britons from the Gauls, both Cæfar and Tacitus deduce from the vicinity of the two countries, and the fimilarity of the manners and character of the people: but a ftronger argument is found in the national appellation of Gael and Gaul, equally attached to both countries. It appears that the inhabitants of Wales were part of the aboriginal poffeffors of the ifland, whofe numbers muft have been greatly increafed by thofe Britons, who, retreating before the victorious Romans, fled to this diftrict, as a dernier refort, to preferve their independence. After the invaders had fecured the central part of Britain, by forming ftations, and appointing garrifons, and had given to it the name of *Britannia Prima*, they turned their attention to the reduction of the unconquered country lying weft of the Severn. When Oftorius, the Roman general, furveyed this country, which he was fent with an army to fubdue, he found it poffeffed by three tribes of people, denominated from their refpective diftricts, Ordovices, Silures, and Dimetæ. The *Ordovices* poffeffed all the country comprifed in the prefent North Wales: the *Silures* occupied the diftrict now comprehended in the counties of Hereford, Radnor, Brecknock, Monmouth, and Glamorgan, and the fmall portion of Gloucefterfhire now weft of the Severn; and had for their capital Caer-Gwent, in Monmouthfhire: the *Dimetæ* were fituated weft of the Silures, and poffeffed the country at prefent including the counties of Cardigan, Pembroke, and Caermarthen. Such were the inhabitants of Wales, when the Romans firft entered it with an hoftile army. Refpecting the condition or ftate of thefe Britons, at the period in queftion, a great difference of opinion prevails among our hiftorians. Some, in defpite of unexceptionable authorities, treat thefe people as illiterate favages, deftitute of cloaths, dwellings, and arts: while others, following the Britifh hiftory, defcribe them as a martial, learned, and flourifhing nation, poffeffing foreign trade, and at home erecting ftately edifices. Both thefe accounts are probably much exaggerated. The beft hiftorians ftate that the Britons had a religion remarkable for its numerous ceremonies; they poffeffed an eftablifhed government; and had regular and well-difciplined troops, divided into charioteers, cavalry, and infantry. With refpect to any great naval power, though attempted to be proved by the learned Selden, well-founded objections may be urged; but as to fmaller veffels, Cæfar bears ample teftimony to the ingenuity of their conftruction, and their great convenience: the facility with which thefe vehicles were made, and their peculiar portability, has occafioned a continuance of their ufe, and *corracles* ftill form the fifhing-boats employed on fome of the rivers of Wales. They had fufficient corn for their fupport, and their paftures were abundantly ftocked with cattle, fheep, and hogs. In their dealing with each other, for money they ufed rings, or fmall plates of iron ftrung together, which paffed among them by weight, as well as tale: fuppofing they poffeffed no minted coins, this circumftance alone would be a fufficient evidence of their civilization; fince it is deducible from hiftory, that no nation in a ftate of barbarifm ever adopted a circulating medium in buying and felling. From the earlieft periods, the Britons breathed a fpirit of genuine freedom, and always ftudied to procure and preferve their liberty. Stimulated by a noble ambition, never to be fatisfied but by victory, nor extinguifhed but by death, they fought with a degree of bravery that aftonifhed the legionary troops; and difputed every acre of ground with a tenacity and obftinacy that extorted from their conquerors the tribute of admiration. Suetonius Paulinus overcame the Ordovices, and extirpated the remainder of the Druids, and their followers, who had fled to the ifland of Mona, or Anglefea. Notwithftanding this, the heroic Silures for years continued their ftruggle for liberty, till at length Julius Agricola was fent with a powerful army by the emperor Vefpafian; and having entirely defeated the Britons under their intrepid leader Caractacus, in a decifive battle near Caer-Caradoc, on the borders of Salop, he completely reduced that part of the ifland to the Roman yoke. The affability of Agricola gained the affections of the people, and difpofed them to imitate the Roman manners: he beftowed on them the privileges of citizens; received them into his armies; provided for the education of their youth; and lived amongft them in a ftyle of great hofpitality. Thus, fecuring by policy what he had gained by force, Cambria was dignified with the name of *Britannia Secunda:* and the conquerors, as they had previoufly done in Britannia Prima, began to eftablifh jurifdictions, and adopt meafures for the due adminiftration of the laws. Towns were built, ftations appointed, and roads formed for communication between them. So fpeedily and fuccefsfully did they proceed in their fettlement of this country, that in a few years Wales affumed all the appearance of a Roman colony. The following ftations were then formed. *Caer Gybi*, Holyhead, in Anglefea;—*Segontium*, Caer-Seiont, Caernarvon;—*Varis*, Bodvary, in Flintfhire, near Denbigh;—*Caergwrle* and *Holt*, alfo in Flintfhire, appear to be fcites of ftations;—*Banchorium*, Bangor-Ifcoed, on the banks of the Dee;—*Heriri Mons*, placed by Stukeley near Bala, in Merionethfhire; but, with greater probability, at Tommen-y-mur, near Feftiniog;—*Caer Gai*, in the vicinity of the former place, feems alfo to have been a ftation;—*Mediolanum*, Meivod, or Myfod, in Montgomeryfhire; three other places in this county feem to lay claim to fuch honourable diftinction, *viz.* *Penalet*, near Machynlleth; *Caer-Sws*, in the vicinity of Newtown; and the *Gaer*, near Montgomery;—*Magna*, Gale and Stukeley place at Old Radnor, but Horfley has removed it to Kenchefter, near Hereford;—*Loventium*, Lanio-ifa, in Car-

diganshire;—*Advigesimum*, mentioned only in the Itinerary of Richard of Cirencester, is supposed by some to have been situated at Castel Fleming, and by others near Narberth, in Pembrokeshire;—*Menapia*, the port for Ireland, near the present St. David's;—*Maridunum*, Caermarthen;—*Llanvar ar y Bryn*, in Caermarthenshire, is evidently the scite of a station;—*Leucarum*, Louchar, or Lougher, in Glamorganshire;—*Bomium*, Boverton, near Ewenny;—*Nidum*, Neath; —*Tibia Amnis*, Caerdiff;—*Gobannium*, Abergavenny, in Monmouthshire;—*Blestium*, Monmouth;—*Burrium*, Usk; —*Isca Silurum*, the capital of the colony, and residence of a prætor;—*Venta Silurum*, Caerwent;—*Ad Sabrinum*, on the Severn, near the new or old passage.

Of the *Roman Roads*, though more distinct traces might be supposed to exist in Wales than in England, from their vestiges not having been equally liable to obliteration from cultivation; yet for want of due investigation, few of them have been traced in a satisfactory manner.—*Via Julia Maritima*, which received the name of Julia, from Julia Frontinus, who successfully conducted the Roman arms against the Silures, is supposed to have connected the stations contained in the eleventh Iter of Richard of Cirencester. This road was a continuation of the Akeman-street from *Aquæ-Solis*, Bath; and directing its course westward across the Severn, passed through Glamorganshire, Caermarthenshire, and Pembrokeshire, to Ad Menapium, near St. David's: few traces of this road have been discovered.—*Via Julia Montana* was an upper road, forming a communication from the more central parts of the island, by the Ryknild-street, coming from Glevum, Gloucester, and passing through part of Monmouthshire, entered the county of Brecknock, proceeded over the mountains to Llanvair ar y Bryn, and thence along the vale to Caermarthen, where it coalesced with the maritime or lower road above mentioned, and both terminated at St. David's.—*Via Occidentalis* appears to have extended along the western coast of Wales, from Ad Menapium to Segontium, and formed connecting links between the intermediate stations.—*Via Devana* takes a direction through the centre of the principality from the southern coast about Nidus, Neath, to Deva, Chester.—*Via Orientalis* took a north-easterly direction from Isca Silurum, to Uriconium in Staffordshire.—A branch of the *Northern Watling-street* entered Wales at Chester, and inclining to the west, passed the station Varis, to Conovium, near Conway.—A branch of the *Southern Watling-street*, extending from Uriconium to Segontium, enters Wales near the village of Llandrinio, and proceeding to Mediolanum. is there met by the Via Devana; it afterwards joins the Via Occidentalis, and continues with it to Segontium. Numerous vicinal roads also traversed the country from station to station, vestiges of which are traceable in various places. A road of communication branched off from the Via Occidentalis at Penallt, and proceeded easterly to Caer Sws. Another road extended north-easterly from Llanvair ar y Bryn towards the station on the river Ython, between which places it is discoverable on the extensive wastes in the vicinity of Llanrindod Wells. From Maridunum, a road leads to Loventium: the construction is evidently Roman, being formed of various stratifications; is about thirty feet wide, and edged with stone. Another may be traced from Llanio, running easterly by Llanvair mountain, and passing through Caio, it goes to Llanvair ar y Bryn, thence to the Gaer near Brecknock, and so to the grand station Glevum, Gloucester. In several places, having the denomination of Sarn, traces of vicinal roads are distinguishable; and wherever this British word occurs, it is probable a Roman road passed near; as Talsarn, Pensarn, and Sarnau in Cardiganshire. Numerous villas, sudatories, aqueducts, walls, milliaria, or mile-stones, statues, votive altars, inscribed stones, tessellated pavements, urns, pottery, bricks, tiles, medals, coins, and various other remains, have been discovered, which evidently point out the vestiges of Roman residence, and by which the occupation of the country by the Romans may be clearly deduced.

Civil History of Wales.—After domineering over Britain above four centuries, the Romans bade a final adieu to the island; which was soon exposed to the inroads of numerous enemies. Assailed on the north by the Picts and Scots, it was equally infested by the Irish on the west. The native strength of the country had been exhausted by war; the number of its inhabitants further diminished by famine and pestilence; and the navy was fallen into decay. Under these disadvantages, the people were also in want of that unanimity so essential in times of emergency. They had recourse to their ancient form of government, and elected for their governors certain reguli, or chieftains; but these, instead of combining to oppose the common enemy by well-concerted plans of co-operation, were principally occupied in securing their separate interests. In this sad situation, without union, order, or discipline, and attacked on all sides by inveterate foes, the Britons adopted the most impolitic of all expedients for national safety,—that of calling in the assistance of one barbarous nation to drive out another; which subjected them to a new and heavier yoke. At this period, besides the many chieftains under whom the island was divided, a personal competition existed between one who tyrannized over the rest and held the sovereign authority, named Gwtheyrn, or (as called by most English writers) Vortigern, and a chief of Roman parentage, called Ambrosius, but by the Welsh, Emrys Wledig. During this contest, Gwtheyrn, to repel the incursions of the Scots and Picts, called in the assistance of the Saxons, an army of whom arrived under the command of Hengist and Horsa, descendants of Woden, the founder of their nation. The Saxon generals having driven back the enemy, and discovered the pusillanimity of the British monarch, turned their attention towards establishing their troops, and securing to themselves a portion of the territories they had defended: this plan, through the treachery or incapacity of Gwtheyrn, they were enabled to accomplish. The enraged Britons deposed Gwtheyrn, and placed Emrys on the throne: he for a time prevailed against the Saxons, but fresh troops arriving under the command of Ella, they became victorious, and extended their territory. On the death of Emrys, his brother Uther, commonly called, from his office, Pendragon, was elected to the sovereign dignity. The intestine warfare was carried on with varied success between the Britons and Saxons; but numerous hordes continually arriving from the north, the latter became formidable in several parts of the island. Arthur, the celebrated son and successor of Uther, for a series of years conducted the war against the invaders; and in many desperately-fought battles led on the Britons to decisive victory. During the reigns of Uther and Arthur, the ancient Britons had attained the meridian of their glory; but it was now drawing to a close: the death of Arthur decided the fate of Britain. Civil dissentions prevailed among the Britons, which were promoted by their crafty adversaries. During these troubles, many of the people submitted to the Saxons and Scots; others, to preserve their freedom, fled to Armorica, which, from the number of the refugees, acquired the name of Bretagne; some retired into the wilds of Devonshire and Cornwall; some took shelter in the mountainous parts of the north of England; but by far the

greatest number found an asylum in the fastnesses of Wales, where they defended and preserved their independence long after the expiration of the Saxon dynasty.

At the period when the Saxons had conquered the greater part of Britain, and made their approaches to the borders of Wales, this country appears to have been divided into six principalities, over which Maelgwyn, king of North Wales, was invested with the sovereign dignity, about the year 552. The contest was continued under several succeeding monarchs, till the death of Cadwallader, in the year 703, closed the imperial dignity, which for many centuries had been annexed to the British government; during which time the paramount princes chiefly resided at Diganwy, on the water of Conway, and at Caer Segont near Caernarvon. Roderic Moelwynoc nominally succeeded to the sovereignty in 720; but by continual and unhappy divisions, the strength of the country was so diminished, as to be unable successfully to resist the incursions of the Saxons. The Mercians, under king Offa, frequently laid waste the country, and at length wrested a portion from the Welsh princes; and to prevent the new occupants from the retaliating vengeance of the Welsh, Offa caused that famous boundary to be made, from the mouth of the river Dee to the Wye, which still goes under the appellation of Clawdd Offa, or Offa's Dyke. By this the region was considerably narrowed, and nearly reduced to its present limits. Though the Saxons made frequent inroads, yet they do not appear to have had any permanent footing in the country; so that though the pages of history record many sanguinary conflicts between them and the Welsh, yet scarcely any vestiges remain to mark the incursions of the invaders. The Danes called off the attention of the Saxons from Wales, which from this circumstance was left for many years in unusual tranquillity, and furnishes but few subjects of historical record during the Danish dynasty. The Danes made some incursions on the coast, but effected no permanent conquest of the country. On the accession of William I. to the throne of England, the Welsh having refused the annual tribute, which had been extorted from them as a mark of submission by king Edgar, the conqueror invaded their country with a powerful army, quickly awed them into submission, and obliged them to do homage, and take an oath of fealty, as due from vassals to their superior lord. From this period the English monarchs preferred a claim to Wales, as their heritable property. On the death of William, the Welsh, feeling the galling yoke of their humbled condition, attempted to recover their lost independence; and joining in revolt with some refractory English barons, entered England, and by fire and sword carried their devastation to the banks of the Severn. These outrages determined William Rufus to attempt the subjugation of the country; and for this purpose he excited his barons to conquer, at their own charge, under homage and fealty to him, the territories of the Welsh. These barons, who were denominated lords marchers, endeavoured to secure their conquests, by peopling them with English, and erecting strong fortresses to defend them from the inroads of the Welsh. Thus was the last asylum of the Britons broken into on every side, and invested by their enemies. South Wales was subdued; while North Wales, now greatly reduced, alone preserved the national character, and supported its independence; and the inhabitants, aided by the valour of their princes, still upheld the struggle; and acquiring vigour from union, dictated by necessity, not only prevented the marchers from achieving further conquests, but rendered their existing acquisitions of precarious tenure. For a long period the Welsh, favoured by the mountainous nature of the country, supported an unequal but spirited contest with their unjust invaders. The death of David, who had succeeded his unfortunate brother Llewelyn, in the reign of Edward I., closed the only sovereignty that remained of the ancient British empire. Edward having at length obtained the object of his ambition, by the entire conquest of Wales, annexed it to the crown of England. He did not, however, for some time, enjoy a tranquil possession; for three insurrections broke out at one time in different places. To such a height did these commotions arrive, that Edward was constrained to conduct the war in person, when he shortly compelled the insurgents to lay down their arms, and make an unqualified submission. These disturbances, the subsequent revolt of sir Gryffydd Llwdd, and the rebellion of Owen Glendowr, were the last efforts the Welsh made to recover their independence. From that period the concerns of the country, till the time of Henry VII., are little interesting; for the inhabitants were reduced to a state of the severest bondage. Henry VII., from the assistance the Welsh had afforded him in obtaining the crown, was more favourably inclined towards them than preceding monarchs, and granted the principality considerable immunities. Several ameliorating statutes were passed in the reign of Henry VIII., to exonerate them from the tyrannical oppressions of the lords marchers; and at length the people, awake to their true interest, solicited the king to give his liberal designs a more salutary effect, by extending to them all the privileges of the English jurisprudence. The prayer of their petition was granted, and Wales was formally united and incorporated with England.

Wales abounds with the remains of encampments, hill-fortresses, castles, and castellated mansions: specimens of military architecture, therefore, in the diversified styles of different and distant periods, constitute some of its most prominent and interesting features. While the Romans generally chose for the scite of their camps, or forts, a rising ground near some river, or a lingula formed by the confluence of two; the Britons selected the most lofty, insulated, and inaccessible mountains, the summits of which they fortified by excavating deep trenches in the solid rock, adding valla, by heaping up the loose stones dug out of the fosses; and in succeeding times, by adding strong walls, and erecting massy circular towers. The Normans introduced a new style of military fortification; and to secure their unjustifiable seizures, and proceed in their aggressions, they erected castles, more formidable both in number and extent, so that what are termed the marches of Wales consist of a series of fortresses from the mouth of the Dee to the embochure of the Wye. Flint, Denbigh, Montgomery, Powys, Brecknock, Caerphili, and Caerdiff, furnish bold examples of the style of those people. More were erected by the Anglo-Normans, as they progressively encroached on the country; for, to secure the conquered possessions from the retaliating vengeance of the expelled owners, they were necessitated to repair and strengthen the fortresses they took, or build others. Thus did these buildings so far increase, that Mr. Pennant enumerates 143 castles in the principality; and that number is probably short of the actual amount. On the conquest of Wales by Edward I., that monarch, who had been crusading in the holy land, and had there imbibed a spirit of eastern magnificence, for the purpose of overawing his new but refractory subjects, constructed three castles in a style, which for strength and grandeur have never yet been surpassed in this country. Harlech, Caernarvon, and Conway, remain the proud monuments of that monarch's age and times.

Ancient Constitution, Government, and Laws.—From the accounts given by the Roman writers, a monarchical form

of government was prevalent among the early Britons. The island was divided into several petty sovereignties, each subject to a separate prince; but in time of emergency and danger, they were united in one, under an officer, similar to a dictator among the Romans, called a pendragon. To him, by joint consent, was committed the whole military government of the independent states. Nor was this dignity temporary, like the power; for though the latter appears to have ceased with the necessity that demanded it, yet the former continued for life, and was hereditary to the male heir. But the right of succession to the separate governments does not seem to be strictly indefeasible; for, in some instances, the lineal succession was violated by the rule of tanistry. By this the king's son, brother, or nephew, became the customary inheritor of the crown; the particular person being selected by the reigning monarch, with the advice of his nobles. This sovereign elect was denominated by the law the tanist, or second in dignity. The Britons were not unacquainted with that rational restraint on monarchical despotism, parliamentary suffrage; for a decisive argument in favour of the existence of British parliaments is found in the preface or introduction to the laws of the great Cambrian legislator, Howel Dda. Six of the most intelligent and powerful persons were summoned out of every cantreff, or hundred, to assist the king in the great work of legislation. This parliament being assembled, proceeded to examine the ancient laws, cancelled some, reformed others, enacted new ones, and digested all into one regular code of jurisprudence. This revision they presented to good king Howel, who having approved it, gave the ratifying sanction of royal authority. Both the monarch and parliament then imprecated the power of the state and the wrath of heaven upon any persons who should violate, or attempt to abrogate, any of these institutes, unless they should be constitutionally annulled in a national council, similar to the one in which they had been recently decreed. From the circumstances of this revision, many of those in the code of Howel Dda were pre-existent statutes, by which the early Britons had been regulated in previous times. From these it appears, that immediately below the sovereign ranked the Uchelwyrs, or great men holding their lands from the crown, and each presiding as lord over his particular domain. As immediate tenants of the king, they were obliged to perform certain services. Inferior to these, and holding from them as feudatory lords, were the general mass of the community, being in a state of villainage, but divided into two classes: first, such as might retain or relinquish their lands at discretion, possessed the power of buying and selling, and whose seignorial service was the least degrading of the menial kind; the other, denominated Caeths, were considered the property of the lord, attached to the soil, and saleable with the estate. These were bound to services the most servile, to build or repair houses for the Uchelwyr, and perform all the drudgeries of husbandry. Both were subject, like the chiefs, to military attendance in time of war, and to contributions in money or kind. Such were the tenures of lands in Wales, prior to the introduction of English customs, as appears by the laws of Howel Dda, not formed by him, but referable to previous institutes, ascribed to the early Britons. And as they were evidently feudal in their essence, and military in their design, the opinion of antiquaries, who deduced the introduction of a system of feuds into this island from the Normans, must be erroneous; for the laws in which it is found to have existed in Wales were collected into a digest, in the early part of the tenth century. The most prominent feature in the Howellian code is the law of inheritance, denominated *gavel kind*, by which the property was divided among the sons; the females of every degree being excluded till the utter extinction of the males, among whom no distinction was made between the legitimate and the spurious. While the Welsh preserved their independence, this law of descent universally prevailed; but on the conquest of the country by king Edward I., he directed certain commissioners to inquire upon oath into all the former laws and usages of the principality; and the first law promulgated by that monarch for the use of Wales was the celebrated statute of *Rhyddlan*. By this he permitted the ancient stem to continue, but lopped off two of its principal branches, *viz.* the admission of spurious offspring to the inheritance, and the preclusion of females. But in the 34th year of Henry VIII., the venerable trunk was for ever levelled with the ground, all the lands in Wales having been required "to be holden as English tenures to all intents." Since which period the laws of England, with the exception of a few formal peculiarities, have continued to form the jurisprudence of Wales.

Ecclesiastical History, Religion, &c.—The religion of the Britons, when Cæsar first visited the island, was of a kind peculiar to them, and to the kindred tribes of Gaul. It abounded with singular tenets, and the mode of worship comprised numerous superstitious rites, the remaining vestiges of which form some of the most interesting antiquities in the country. *Bardism*, or the Druidical system as it is generally called, has been variously represented; and the term *bard*, given to the Welsh poets who were not of the Bardic order, has tended to increase the confusion on the subject. What may be considered as the foundation of the order was the principle of universal benevolence, so that a bard was prohibited by his tenets from bearing arms; and being recognised as the herald of peace, he could pass, when clad in his azure robe, unmolested from one hostile country to another. The bards were divided into three classes, the *bard braint*, *ovydd*, and *derwydd*. To the bards braint belonged the perpetuation of the customs and privileges of the system, and of its moral and civil institutes; the ovyddon, or ovates, particularly attended to the cultivation of the arts and sciences; the derwyddon, or *druids*, were the priests who officiated in religion: from which circumstance, and from the great influence they consequently obtained over society, this class was most conspicuous, and became the general denomination of the whole.

Their origin, learning, religion, authority, revenues, decline, and extinction, have been fully detailed in this work under the article DRUIDS.

In the sixth century, the archiepiscopal seat of Wales was removed from Caerleon to Menevia, which was subsequently known by the appellation of St. David's. At that time the archbishop had under him three suffragans, the bishops of St. Asaph, Bangor, and Landaff. In the tenth century, St. David's lost its archiepiscopal honours; and in 1101, it became subject to the metropolitan see of Canterbury; to which, on the subjugation of the country by Edward I., the whole of Wales, as to ecclesiastical affairs, submitted; and at the dissolution of monasteries, the Welsh having been subjected to the English laws, the clergy in Wales were brought under the same regulations as those in England. And from the close incorporation of the two countries, the history of the church, after that time, is nearly similar in both. In Wales are many sects of what are considered regular Protestant dissenters from the established church, which had their rise in the reigns of James I. and Charles I., and more especially during the protectorate of Oliver Cromwell. But the greatest number of seceders from the established church are the different descriptions of Methodists, whose places of

assembling, multiplied over the face of the country, receive the appellation of chapels. Of this increasing dissent, one reason is assigned to be the generally illiterate state of the regular clergy: for most of the livings in Wales are so small, and the stipends of curates so scanty, that no inducement is held out for youth being properly instructed for the ministry, and consequently the churches must be served by incompetent ministers. But this evil is likely soon to be remedied; for by the zealous endeavours of the present worthy bishop of St. David's, two seminaries are instituted for the education of youth designed for holy orders, who are provided with tutors. Most places in Wales have the benefit of a free-school; and in the year 1749, for the instruction of the children of the lower orders, 142 itinerant schoolmasters were appointed by the society for promoting Christian knowledge. Those among Protestant dissenters have been provided for in this respect by the pious bequest of Dr. Daniel Williams, many years the respectable pastor of a congregation in London, who left a large sum of money for establishing charity-schools, where such institutions were wanted; by virtue of which the trustees have erected many in the principality.

The lovers of *ecclesiastical, monastic*, and *sepulchral architecture*, will find ample scope for amusement and admiration, in the remains of religious edifices, both in an integral and dilapidated state, still visible in various parts of the principality.

Mountains, Lakes, Rivers, and Climate.—Wales exhibits all the features of a detached district from England, consisting of almost continued ranges of lofty mountains, and impending crags, intersected by numerous deep ravines with extensive valleys, and affording endless views of bold, wild, or romantic scenery. To enumerate the mountains which are nominally known to the natives, and form very striking objects to the traveller, would be superfluous; but a general view of them, as they are grouped with multifarious ramifications, may be useful. The chains generally extend in a direction from south-east to north-west, having their escarpment, or most abrupt declivity, on the latter bearing. Numerous projecting ridges laterally expand on various parts of the compass, in countless ramifications, many of which are surmounted by lofty eminences, that are formed into so many distinct mountains, so that, like the Alps, they seem to be mountain piled upon mountain, and hills conglomerated upon hills. The principal range in North Wales is that denominated the *Snowdonian* chain, from the lofty mountain Snowdon occupying its centre. Commencing at Bardsey island, in the south-west extremity of Caernarvonshire, the line, varied at irregular intervals by conical peaks, extends in a north-easterly direction to the promontory of Penmaen-bach, in the bay of Conway. The intermediate parts consist of the loftiest mountains in Wales. The *Ferwyn* chain occupies the eastern part of Merionethshire, and branches out into Denbighshire. Its length is about sixteen miles, and the breadth varies from five to ten: Cader Ferwyn, Cader Fronwen, and the Sylattin, are the most elevated points. Another line branches off into Montgomeryshire, and joins the Breddin chain, extending into Shropshire. Another chain, or rather a continuance of the same, extends in a south-west direction from Pennant, near the vale of Tanad, in Montgomeryshire, to the sea-coast near Langyllinin in Merionethshire. In this extensive ridge are conspicuous several lofty mountains, known under the appellation of the Arrans and the Arrenigs; the most eminent of which are Arran-ben-llyn and Arran-fowddy, and the extremity of the line is grandly marked by the triple head of the lofty Cadir Idris. The celebrated *Plinlimmon* proudly elevates his crest above a range of table land, extending from the vicinity of Llanvair in the north-east, till they decline in the south-west, and end in the abrupt cliffs, which bound part of the bay of Cardigan, near Aberystwith. Among particular elevations in this line, after the sovereign of the group, the Carno mountains stand the most pre-eminent. South Wales, though not equally mountainous with the northern part of the principality, nor so distinguishable for its Alpine heights, is yet far from being deficient in elevations and depressions. An extensive chain of mountains stretches from Bleddva forest, north-east of Lhandrindod Wells, in Radnorshire, crosses the northern part of Brecknockshire, continues in a south-westerly direction through Caermarthenshire, and terminates in the conspicuous ridge of the Prescely or Prescelau mountain in the county of Pembroke. The Fothoc hills, on the eastern side of Brecknockshire, commence another line, principally known under the general appellation of the *Black Mountains*, from the appearance given to them by the dark vegetable covering of heath and ling. Among individual elevations, remarkable for their height, are Tre-beddw mountain, Pen Mallard hills, the black mountains strictly so denominated, and the high table land which in the south part of Caermarthenshire is closed by the isolated mountain, called Pembre hill. In this mountainous region, *lakes* are exceedingly abundant; an attempt to describe, or even to enumerate them, would be endless: Mr. Gough reckoned from fifty to sixty in Caernarvonshire only. The most distinguished for extent, or the beauty of the surrounding scenery, are, in North Wales, Lynian Nantle, Llyn Cywellin, Llynian Llanberris, and Llyn Conway, in Caernarvonshire; with Pimble-meer, and Talyllyn, in Merionethshire. In South Wales, Llyn Bychlyn, in Radnorshire, and Llyn Savathan, or Langor's pool, in the county of Brecknock.

Rivers.—Wales, though a mountainous country, is equally remarkable with England for its numerous streams, which issuing from considerable lakes, or aided by their waters, meander through the country, and form excellent harbours at their confluence with the sea. The principal rivers are the Severn, the Wye, and the Towy, in South Wales; the Conwy, the Clwydd, and the Dee, in North Wales: these have not only attained pre-eminence in fame for the utility of their navigation; but, by poets, have been celebrated in song. The former constitutes the eastern, and the latter the north-eastern boundary of the country, between the embochures of which many others, though less distinguished in a commercial point of view, are highly valuable for their fisheries and other properties. These, tracing their sources in the order in which they unite their waters with the ocean, are, in North Wales, the Ogwen, Sciont, Gwynedd, Drwydd, Avon, and Dovey; in South Wales, the Rheidiol, Ystwith, Eiron, Tivy, Nevern, Gwyn, Cleddy, Itrog, Taf or Tave, Loughor, Tawy, Nedd, Avon, Taf or Taffe, Rhymny, and Usk. A particular description of the most considerable, will be found under their respective names.

The *climate* of Wales differs materially from that of the portion of England, lying in the same parallel of latitude; and assimilates more with the northern parts of the island. In a general view the air is sharp; in the mountainous parts bleak; moderately mild in the vales, and those parts adjacent to the ocean, especially on the southern coast, and particularly in the celebrated vale of Glamorgan. From the greater degrees of cold prevalent in the Cambrian atmosphere, snow is more frequent in Wales than in England, lies much deeper, and is seen covering the tops of the highest mountains, for many months in the year. The wet season in this country is not usually confined to the winter months;

for rains are frequent at all times of the year. The gaged quantity of rain which annually falls in England, according to the experiments of Dr. Hales, is about twenty-two inches; while the average that deſcends in Wales may be eſtimated at thirty-four. From numerous obſervations reſpecting this ſubject, the reſult has uniformly been, that more falls on the weſtern than on the eaſtern ſide of the kingdom, and moſt in the mountainous diſtricts; conſequently Wales muſt participate largely in ſuch an exceſs of humidity. In the year 1802, the quantity of rain which fell in London was fifteen inches, and in Brecon twenty-ſix inches. Moiſt as the climate of Wales muſt conſequently be from this vaporous ſtate of its atmoſphere, yet the air is in general highly ſalubrious, and the country healthy. Scarcely a cemetery in the principality, but bears ſome teſtimony to the longevity of the inhabitants, even to the protracted age of a century, and in ſome inſtances even to a greater extent.

Natural Productions and Minerals.—Few countries can vie with Wales in the multifarious variety of its productions, while none perhaps have been ſo long and undeſervedly neglected. Some animals, rarely to be met with, frequent the wilds of this diverſified country. The goat is here found in its ferine ſtate, and is far ſuperior in ſize, and in the length and fineneſs of his hair, to that of moſt other mountainous countries. Though this uſeful animal has been long domeſticated, yet many of the inhabitants of North Wales ſuffer the goats to run in a wild ſtate, and bound from crag to crag. Theſe they are accuſtomed to kill during autumn for the ſake of the fat and ſkins: thus goat-ſhooting and goat-hunting are ſtill practiſed by the people in Wales. Roebucks were anciently numerous, but are now confined to the moſt intricate parts of the country, and they are rarely to be ſeen. Of the feathered tribes, many ſpecies, not found in other parts of the iſland, are to be met with here. The golden eagle is an inhabitant of the Snowdonian mountains, which thence are ſuppoſed to have derived their appellation of the Eagle rocks. The peregrine falcon, ſuppoſed to be the bird which furniſhed the amuſement of falconry to our anceſtors, and formed a ſort of criterion for nobility, breeds abundantly among the rocks of Llandidno, in Caernarvonſhire. The merlin, uſed in hawking, migrates from Wales to England generally in September. The water rail is found in Angleſea, early in the ſpring; and immenſe flocks of puffins viſit the iſland of Prieſtholme about the ſame time. The guillemot, and the black-backed gull, frequent the Welſh coaſt during the winter. Among the numerous fiſh, which abound in the rivers of Wales, in addition to thoſe generally known in England, may be noticed the crooked perch found in Llyn Raithlyn, Merionethſhire, and the deformed trout, ſaid to be peculiar to a brook, called Syrcian, in Cardiganſhire: (theſe two ſpecies are deſcribed by Daines Barrington, in a communication to the Royal Society 1767): alſo the ſamlet is frequent in the upper part of the Severn and the Wye; the ſewin, the red char, the ſilver char, and the gwiniad. Some of theſe, however, are not excluſively peculiar to the principality, but are found in ſome of the rivers of Scotland, and in the lakes of Weſtmoreland and Cumberland.

The *mineral* productions of Wales form the moſt intereſting part of the ſubject, and furniſh an inexhauſtible ſource of profitable inveſtigation to individuals, and of national wealth. The mountains and hills may be ſeparated into three diſtinct claſſes, *viz.* primitive, ſecondary, and derivative, which in a general view may alſo be diſtinguiſhed by the peculiarities of their form, as well as their relative ſituation. Primitive granite mountains conſiſt of craggy ſteep rocks, tending in the aſcent more or leſs towards an acute or ſlender pointed ſummit, the loftieſt mountains are centrically ſituated in the chain, which commencing and terminating in abrupt precipices, with the inſulated peaks that interrupt the general outline, form a ſtriking and diſtinctive character. Secondary mountains, chiefly compoſed of ſchiſtoſe ſubſtances, range next in the ſcale, and are diſtinguiſhable from the former by their inferior height, the evenneſs and ſquareneſs of the individual links which compoſe the chain, and by the eaſy waving though varied line of the general contour: inſtances of which are conſpicuous in the Ferwyn and Breddin mountains previouſly noticed. Derivative, or calcareous and ſiliceous hills, range conſiderably lower than the ſecondary or ſlate mountains, uſually riſing by a gradual aſcent at one extremity, and terminating abruptly at the other. The lime-ſtone hills frequently aſſume a pyramidical ſhape, while the ridges of the ſand rocks, and banks, are broader and rounder than thoſe of lime. Theſe, however, often trap into each other, and then little diſſimilarity is diſcoverable in their form. The primitive mountains in maſs contain no metals; copper is however found in ſeveral of the horn-ſtone ſtratified mountains, of which the Parys mine, and thoſe at Llanberis and Pont-Aberglaſlyn, are examples. In theſe mines, the ore is for the moſt part yellow, ſulphuret of copper, the green and blue malachites or carbonates of copper, are found in lime-ſtone, as at Ormes-head and Llanymynech hill, where copper is not produced in any other ſtate but that of carbonate, which is alſo found in the calcareous cement of ſand rocks. The ſtrata generally moſt productive of the metallic ores are lime-ſtone; and moſt ſpecies of whin-ſtones, or the argillaceous mountain rocks, of which there are many varieties appearing in thick, thin, and mediate ſtrata; ſome of theſe rocks are moderately and others exceedingly hard. They aſſume various colours, though principally one or other of the numerous ſhades of grey. Several rich and valuable mines are diſcovered in granite or moor-ſtone mountains. Theſe three orders or claſſes of rocks, with their concomitant ſtrata, are uſually interſected by mineral fiſſures, and contain the largeſt quantity of mineral ſubſtances, and metallic ores. But of all claſſified ſtrata, in which the richeſt mineral veins have been diſcovered, the indurated argillaceous mountain rocks are the moſt prolific and extenſive. Many of the mines in North Wales, nearly the whole of the numerous valuable lead mines in the county of Cardigan, and moſt of the mines in other parts of South Wales, are found in this kind of matrix or ſtrata. The principal ſubterraneous ſubſtances produced in Wales, may be divided into three claſſes, metalline, mineral, and lapideous; and the places where they are dug receive the diſtinctive appellations of mines, pits, or quarries. *Silver* is obtained in conſiderable quantities, though not at preſent found in what may be excluſively denominated ſilver mines. Cwmſymlog mine in Cardiganſhire conſiſts of ſilver ore, lead ore, and quartz; which, from the rich produce of the more precious metal, received the appellation of the Welſh Potoſi. Daren vawr, Daren vach, Goginan Cwm Evyn, and Mynydd bach, contain ſimilar ſubſtances to thoſe of Cwmſymlog, though not equally productive of ſilver. Llanvair is at preſent the richeſt mine worked in the principality; compriſing ſilver, lead, quartz, ſpar with a ſmall portion of copper, and yields about one-ſixth of lead ore. About ſixty to eighty ounces of ſilver are extracted from a ton of ore, and twelve hundred and a half weight of lead. *Copper*, which was known and appreciated by the Romans while in poſſeſſion of Britain, is abundant through different parts of the iſland, but was not an object of commercial inveſtigation till within

about two centuries paſt; nor in Wales to any conſiderable purpoſe till the middle of the laſt. The copper works of the Romans lay for ages neglected; and to the public and enterpriſing ſpirit of Nicolas Bailey, the country owes the revival of reſearch for this valuable metal. Parys mountain in Angleſea conſiſts wholly of copper, either in a ſtate of native copper, ſulphate, black ore, or malachite: the matrix is a dark grey chertz, and the ſuperſtratum aluminous ſlate. The copper ore found at Llanberris in Caernarvonſhire, is of a very ſuperior quality to that of Parys mountain, yielding from eight to ten *per cent.* weight of metal. This ore ſubſiſts in the primitive ſtratified rocks, and generally in a matrix of ſchiſtoſe hornblende, or quartz. The ſame mountainous ridge, conſiſting principally of whin and horn-ſtone, divided by the immenſe chaſm over which is thrown the bridge called Pont-aberglaſlyn, contains another copper mine producing ore ſimilar in quality to that of Llanberris; and it is highly probable the whole of this diſtrict is pregnant with copper. Eſcair vraith mine in Cardiganſhire conſiſts of copper ore, ſpar, quartz, and a ſubſtance, termed by the miners gozin, which forms an envelope to the quartz. *Lead*, for which this iſland was always famous, is found in a variety of places through Wales, but particularly in the counties of Flint, Caernarvon, Montgomery, Caermarthen, and Cardigan; indeed the latter may be conſidered as the moſt extenſive and richeſt mining field in Britain. A mineral tract ſtretches from Pen-yr-allt, or Bryndigri, in a line to the weſtern borders of the pariſh of Holywell in Flintſhire, and is known under the name of Whiteford rake. The ores differ in quality; the lamellated, or common kind, uſually named potter's ore, yields from fourteen hundred to ſixteen hundred and a quarter of lead, out of twenty hundred of the ore: but the laſt produce is rare. The veins are found either in chert or lime-ſtone rocks, and ſome of the beſt ore has been dug at the depth of ninety yards. In this tract ſeveral levels have been driven and ſhafts ſunk, and lead continues to be obtained in very conſiderable quantities. Between Gwydir and Capel Cerrig in Caernarvonſhire, within an extenſive dip between lofty mountains, are very extenſive lead works. The ſurrounding rocks conſiſt of ſlate, bituminous ſhale, and trap or whin; the matrix of the ore is quartz, and calcareous ſpar; they produce lead and calamine, mixed with iron ochre, and a ſmall quantity of copper pyrites. Theſe different ſubſtances are ſo blended, that in the ſame ſpecimen a variety of them may be found. But Cardiganſhire may be peculiarly denominated the region of lead mines, the whole country apparently having its rocks cemented together with veins of this metal. For a vaſt extent the land is excavated, and the ſurface covered with the opening of mines already worked, or the veſtiges of numerous others that have furniſhed their ſubterraneous treaſures to remote generations. The principal lead mines in this county are Cwm-yſtwyth, Llewerneg, Inys Cynvelin, Penybanch, Bron-y-goch, Llwyuwnwch, Grogwuion, Gellan Erin, and Nant-y-Crier. The ore found in moſt of the Cardiganſhire mines is nearly of a ſimilar nature, conſiſting chiefly of lead, mixed with quartz and ſpar, accompanied frequently with quantities of an ore of zinc, denominated by the miners, from its dark appearance, black jack. This, which formerly was appropriated to the repair of the roads, has lately been diſcovered to be a valuable article, conſtituting an excellent flux for braſs; and, mixed in due proportions with copper, makes a hard metal, ſimilar to the orichalcum of the ancient Romans. *Iron*, the moſt uſeful, and through the wiſe diſtribution of Providence, the moſt common of all metals, is plentifully diſperſed over the Britiſh iſles; and Wales is not deficient in this particular. Yet, notwithſtanding the mountains of this country are full of iron-ſtone, it was not till within about half a century, that the public attention was turned to this inexhauſtible ſource of internal wealth. Iron is moſt abundant in South Wales, though evident marks of its exiſtence may be traced in North Wales; and it has lately been procured, and works erected in the vicinity of Ruabon in Denbighſhire. The ſeveral ſpecies of iron which have been diſcovered are hematites, kidney ore, or compact brown iron-ſtone; grey ore, or black iron-ſtone; bog ore ſwampy iron-ſtone; and a variety of ſulphurated and arſenical ores, which claſs under the general denomination of pyrites; but the kidney and grey ores are the moſt frequently found. The principal iron works are Merthyr Tydvil, Aberdare, and Cyfartha, in Glamorganſhire; and the Union, Llanelly, Beaufort, and Hirwan, in Brecknockſhire. *Coal* is found in every county of Wales except Cardigan, Merioneth, and Caernarvon. The coal ſometimes underlays the calcareous ſtrata, or, in the miner's phraſe, has a lime-ſtone roof; but more frequently it is found on the northern or ſouthern ſide of a lime-ſtone ridge; and when a tract of low land is included between two ſuch ridges, it may be inferred, that coal lies beneath. Two parallel lines of calcareous ſtrata extend through South Wales in an eaſterly direction, from St. George's Channel acroſs the whole country. Theſe are accompanied by two lines of coal. Upon the upper line, coal has been found at Johnſton, Picton, Jeffreſton, and Begeley, in Pembrokeſhire. Thence keeping on the ſouthern ſide of the lime-ſtone ridge, it croſſes the Towy, forming the bar at the mouth of that river; and paſſing through the upper part of Caermarthenſhire, Brecknockſhire, and Monmouthſhire, croſſes the Severn to the collieries of Kingſwood near Briſtol. The different ſpecies of coal in Wales are the newcaſtle, the rock, the ſtone, or ſplent, the cannel, or parrot, and the culm, or blind coal, denominated in England Welſh coal, becauſe almoſt peculiarly the produce of Wales. Some varieties of the cannel coal are ſo fine and ſolid in the contexture, and ſo ſuſceptible of a high poliſh, as to be capable of being turned in the lathe, and formed into various utenſils, toys, and trinkets. The ſchiſtoſe mountains of Wales afford another ſubſtance, if not of equal importance, yet of general utility. *Slates*, cuſtomarily called Corniſh tile, becauſe originally procured from Cornwall, conſtitute an elegant and uſeful roofing to houſes much cheaper than lead, for which it is latterly become a very common ſubſtitute. Slate quarries are numerouſly ſcattered over the country, but the principal are thoſe of the Rheidiol near Aberyſtwith, Cardiganſhire; Llangynnog, Montgomeryſhire; and the extenſive ones in Snowdonia, Caernarvonſhire. Thoſe of the former place produce ſpecimens of the large and coarſeſt kind of ſlate, which lie in compact maſſes, reſembling flag-ſtone, of a rough texture, but ſeparating eaſily into large plates. Llangynnog ſlate alſo divides into large plates, is not of quite ſo coarſe a quality, and forms a very profitable building article. Theſe quarries, Mr. Pennant obſerves, yielded from November 1775 to the ſame month in the following year 904,000 ſlates, which were ſold from ſix to twenty ſhillings per thouſand. The Snowdonian ſlates are generally of a very fine grain, a beautiful blue colour, and when quarried ſeparate into exceedingly thin laminæ; properties, which render them particularly eligible for handſome roofing, and manufacturing into writing ſlates. So great have been the quantities of late years procured from this diſtrict, that a ſmall inſignificant creek has been dignified with the name of Port-Penhryn, from the export trade of this article only. On viewing the different apertures of the ſchiſtoſe moun-

tains, a ſtriking geological fact will reſult, correſpondent with the principle of uniform though unequal declivity. It is obſervable that the ſlates are always coarſeſt in their texture on the northern or north-weſtern ſides of the ridge, and leſs ſo on the ſouth and ſouth-weſtern ſides; becoming gradually finer as they approximate the lime-ſtone hills. Wales affords numerous quarries of other valuable ſtones; *viz.* different kinds of marble fit for monuments, columns, chimney-pieces, and other ornamental ſculpture; ſerpentine and other ſpecies of horn-ſtone; chert or petriſolex, and pure quartz, for the uſe of the potteries. Nor ſhould that rare and curious ſubſtance be omitted, which furniſhes the aſbeſtus, indeſtructible by fire, found on the ſhores of Angleſea. The mona marble, from the iſle of Angleſea, is now much uſed in chimney-pieces and fancy furniture. (See MARBLE, *Britiſh.*) The Britons, as already obſerved, underſtood the uſe of metals, and were further inſtructed in the arts of mining by the intelligent Romans; but after the departure of the latter, ſelf-preſervation occupied the attention of the natives, and peaceful ſcience ſunk under the devaſtating hand of war. Yet their mines were not wholly neglected, for it was probably by means of this ſubterraneous wealth, that the Welſh were enabled to ſupport againſt the Engliſh an unequal warfare for ſo long a time. During centuries after the conqueſt, in England the crown aſſerted its excluſive right to all mines and minerals; and no perſon could ſearch for ore unleſs empowered by a royal grant, under conditions impoſed at the diſcretion of the monarch. Edward I., on his conqueſt of Wales, extended his mining authority over that country; and it does not appear that the proprietor of the land, on which a mine was opened, had any ſhare in the profits, till the reign of Henry VI., when the duke of Bedford having obtained a leaſe of all mines containing any gold or ſilver, a reſervation was made of a twentieth part of the proceeds to the owner of the land. Queen Elizabeth, however, adopted a ſound policy: ſhe ſent over for ſome experienced Germans, and granted letters patent to them and their heirs for ever, to ſearch for and conduct the buſineſs of mines, through ſeveral ſpecified Engliſh counties, and the whole principality of Wales. The patentees divided part of their tenure into ſhares for ſale; and with the purchaſers of ſuch ſhares, they were incorporated by the ſtyle of the "governor, aſſiſtants, and commonalty of the mines royal." But though the foundation was thus laid for the preſent ſucceſs in mining, yet little of importance was effected till the reign of Charles I. According to the teſtimony of Schlutter, the lead mines in Flintſhire were not worked before the year 1698, when Dr. Wright and his aſſociated adventurers eſtabliſhed a ſmelting-houſe at Halkin. The ſubſequent extenſion of mining concerns was encouraged by the repeal of former reſtrictive ſtatutes, and by the enactment in the firſt year of William and Mary, that perſons having mines ſhall enjoy the ſame, although claimed as royal mines; the king having the right of pre-emption in the ore at certain regulated prices.

Agriculture, Bridges, Roads, and Canals. Wales in a general view may be conſidered a century, at leaſt, behind England in its ſtate of agriculture. The mode of ploughing, the courſe of crops, the deficiency of manure, the want of draining, and the rude implements of huſbandry, are ill calculated for making a progreſs in agricultural amelioration. Many of the errors evidently ariſe from the ignorance, prejudice, indolence, and poverty of the tenants; but other cauſes are attributable to the proprietors of eſtates. One is, not granting proper leaſes, the lands for the moſt part being let from year to year: a ſtill more injudicious cuſtom is the letting farms by auction. But though this is the general ſtate of agriculture, yet ſtriking and honourable inſtances occur, in divers places, of more rational conduct. Many gentlemen are ſetting the example of the moſt improved practice; and almoſt in every county, aſſociations of intelligent agriculturiſts have been formed for the introduction and encouragement of a better ſyſtem of huſbandry. From the nature, as well as number of the rivers in Wales, the erection of bridges muſt have excited, at an early period, the attention of the Welſh. Inſurmountable barriers muſt have been oppoſed to the traveller, without the aid of what may be termed pendent bridges; that is, ſuch as are thrown from crag to crag, at a prodigious height above the water. Of this kind is the bridge, or rather two bridges, called Pont-ar-Mynach, near Hafod, in Cardiganſhire, forming a paſs over an awful yawning chaſm, through which the river rolls its waters to the Rheidiol. Another, called Pont-aber-glas-lyn, forms a communication over a narrow defile in the mountainous ridge ſeparating the counties of Caernarvon and Merioneth. Numerous bridges, of a ſingle arch, are ſcattered over the country; of this claſs is the celebrated Pont-y-Prydd, croſſing the boiſterous Taffe in Glamorganſhire. Among thoſe bridges compoſed of more than one arch, the triangular-arched bridge over the river Dee at Llangollen, is curious for its mode of conſtruction, and great antiquity: the bridge acroſs the Conwy, near Llanrwſt, is an elegant ſtructure, and does honour to the ſkill of its architect, Inigo Jones: the bridge of five arches at Bangor-iſcoed, in Flintſhire, is a fine ſpecimen of architecture. The town of Caermarthen is entered by a long ancient bridge; but the ſtupendous aqueduct, by which the continuation of the Elleſmere canal is carried over the Dee, at Pont Cyſſyllte, between Llangollen and Chirk, in Denbighſhire, is the chef d'œuvre of this ſpecies of architecture; and can only be exceeded in grandeur or utility, by the projected bridge over the Menai ſtraits, by which it is propoſed to form a land communication between the county of Caernarvon and the iſland of Angleſea. Wales, though long famed for its bridges, was, till of late years, nearly a ſtranger to good roads. Except the two great mail-roads, forming the communication with the north and ſouth of Ireland, by the way of Milford and Holyhead, whence the packets ſail for that country, ſcarcely a road could be found, calculated for the paſſing of carriages. But to this eſſential point for profit and convenience, the land proprietors have recently directed their attention with the moſt beneficial effects; and the country may now be traverſed in almoſt every direction. Under the auſpices of that public-ſpirited nobleman, the late lord Penrhyn, a grand road has been cut through the immenſe range of lofty mountains, denominated Snowdonia, by which an extenſive communication has been opened between the internal parts of North Wales and the coaſt; and the great thoroughfare from London to Dublin by way of Holyhead diminiſhed in length, compared with the former one by way of Shrewſbury and Conway, twenty-five miles. Numerous roads have been widened, ſhortened, and otherwiſe improved, by the addition of drains, arches, bridges, &c. to the great accommodation of travellers, and general benefit of the inhabitants. Already has the country begun to experience the advantages by new communications having been opened for the produce of the interior, in the reduction of the rate of carriage, and in the eaſy acceſs thus afforded for the conveyance of ponderous articles to the ſea-coaſt, or to the inter-communications with the navigable rivers by inland canals.

Improvement by internal navigation was long neglected in this country, though equally capable of ſuch advantages

as England. In North Wales, the firſt project which engaged the attention of the landed intereſt, was the junction of the navigation on the rivers Severn and Dee, by opening an aquatic communication through the counties of Denbigh and Flint, with various ramifications into the mining and manufacturing diſtricts in the adjacent counties. This is called the Elleſmere canal, connected with which is the Montgomery canal. Thoſe in South Wales are the Kidwelly, Cardiff and Merthyr Tydvil, Aberdare, Neath, Brecknock, and Swanſey canals. For a particular deſcription of each, ſee their reſpective names under the article CANAL.

Manufactures, till within theſe few years, were not very extenſively diffuſed, nor could be conſidered of much account in the general ſcale of productive induſtry. Wales, however, has for centuries been celebrated for its flannels, and may be conſidered as ſtanding unrivalled in this uſeful article. The woollen ſubſtances manufactured are webs, flannels, ſtockings, wigs, gloves, and ſocks. Webs are diſtinguiſhed by the trade into two ſorts; the ſtrong or high country cloth, and the ſmall or low country cloth. Strong cloth is made in Merionethſhire, and principally in the vicinity of Dolgelly and Machynlleth: at the latter place is a manufactory upon a ſmall ſcale, a circumſtance only worthy of notice, as forming the commencement of a change in preparing the wool, which will probably ſoon become general. The ſtandard width of this cloth is ſeven-eighths of a yard; the length of a piece, or what is emphatically ſtyled a web, is about 200 yards; the quality is of various degrees. Small cloth is the produce of Denbighſhire; it is chiefly manufactured within the pariſh of the Glynn, a large tract of country including Llangollen and Corwen. This article is about one-eighth of a yard narrower than ſtrong cloth; the length is the ſame. Flannel conſtitutes the moſt important of the Welſh manufactures: it is chiefly the produce of Montgomeryſhire; but by no means confined to that county, being made in various places within a circle of about twenty miles round Welſhpool. A manufactory of note has been eſtabliſhed a conſiderable time at Dolobran; and two on a large ſcale have been recently erected near Llanydloes, where the various machines, uſed in the woollen trade by the Engliſh, are applied to the purpoſes of manual labour. The principal markets for webs and flannels are Welſhpool and Shrewſbury; the quantity made is not eaſily aſcertained. Mr. Pennant, in his Snowdonia, publiſhed in 1781, mentions, that there were brought "annually to Salop 700,000 yards of webs; and to Welſhpool annually between 7 and 800,000 yards of flannel." Stockings, wigs, ſocks, gloves, and other ſmall knit articles, are ſold chiefly at Bala, Merionethſhire, being made in that town and neighbourhood. Stockings, to the amount of from two to five hundred pounds worth, are ſold each weekly market-day. Very conſiderable manufactories of cottons and cotton twiſt have been eſtabliſhed in the counties of Flint and Denbigh, the principal of which are Northop, Greenfield, Sceiving, Newmarket, and Denbigh. In ſome of theſe factories cotton yarn is ſpun of ſo fine a texture, that 130 hanks, each being 830 yards in length, make but a pound weight. Numerous manufactures of copper, iron, lead, tin-plates, &c. have alſo been recently ſet up in various towns both in North and South Wales. *Commerce* may juſtly be conſidered at preſent in its infancy, being chiefly confined to the coaſting trade. Except Caernarvon and Swanſea, which have lately extended their views to Spain, Portugal, and the Weſt Indies, few of the Welſh ports poſſeſs veſſels of very conſiderable tonnage; though no part of the iſland contains a greater proportion of harbours and roads, ſome of which are ſafe and good, and more might ſoon be made ſo, by the building of piers and other improvements, which are obvious at the reſpective places.

Peculiar Cuſtoms, Superſtitions, &c.—Among a variety of Welſh cuſtoms, thoſe in courtſhip, marriage, and at funerals, excite particular attention. Hymeneal negociations are frequently carried on by the Welſh peaſantry in bed: the young ſwain goes ſometimes ſeveral miles to viſit the object of his choice at her reſidence; the lovers retire to a bed-chamber, and between the blankets converſe on thoſe ſubjects which the occaſion ſuggeſts. This uſage is confined to the labouring claſſes of the community; and is ſcarcely ever productive of thoſe improprieties which might naturally be expected. Previous to the celebration of a wedding, a friend undertakes the office of a bidder; who goes round the neighbourhood to invite all perſons of nearly the ſame ſituation of life as the contracting parties: in conſequence, the friends and neighbours for a great extent make a point of attending the wedding, laden with preſents of money, butter, cheeſe, and other proviſions; theſe are carefully recorded by the clerk of the wedding, oppoſite to each reſpective name, and are to be repaid in the ſame public manner, on ſimilar occaſions, whenever demanded. This cuſtom is called *pwrs a gwregys;* and making the preſents is termed paying *pwyddion.* As an ancient uſage, it is conſidered as recoverable by law; but a ſenſe of the reciprocal duty generally prevents litigation. Funerals in Wales are attended by greater crowds of people than even their weddings. When the proceſſion ſets out, every perſon kneels, and the miniſter repeats the Lord's prayer. At every croſs-way, the ſame ceremony is repeated, till they arrive at the church; the intervals of time being filled up by ſinging pſalms and hymns. A remarkable cuſtom prevails, in ſome parts of Wales, of planting the graves of departed friends with various evergreens and flowers. Box-thrift, and other plants fit for edging, are planted round in the ſhape of the grave for a border, and the flowers are placed within, ſo that the taſte of the living may be known by the manner of embelliſhing theſe manſions of the dead. The ſnow-drop, violet, and primroſe, denote the infant duſt; the rocket, roſe, and woodbine, ſhew maturer years; while tanſey, rue, and ſtar-wort, mark declining life. Each has its little evergreen, fond emblem of that perennial ſtate where change is known no more. It has been obſerved, that mountainous ſcenery is peculiarly friendly to thoſe aerial and imaginary exiſtences which conſtitute the objects of ſuperſtition. This is exemplified in Wales. The belief of witchcraft is ſtill ſtrong, and many are the fatal effects ſuppoſed to be produced by ſupernatural agents: at every houſe may be ſeen a horſe-ſhoe, a croſs, or ſome charm of defence. Many old women, on account of their age, and perhaps deformity, bear the odium of preventing the cows from yielding milk, and of inflicting diſorders on men and cattle. The ſuppoſed witches find it their intereſt to deny nothing that is alleged to them; and thus become held in ſuperſtitious fear by the people, and obtain a livelihood from their imagined extent of power. The belief of thoſe elvine beings called fairies appears to have been ancient and general, and is not yet wholly eradicated. In ſome degree connected with fairies, is another ſpecies of ſuppoſed aerial beings, called knockers: theſe, the Welſh miners ſay, are not to be ſeen, but are heard under ground, in or near mines, and by their noiſes, which repreſent the different ſtages in the progreſs of mining, generally point out to the workmen a rich vein of ore. An opinion is prevalent within the dioceſe of St. David's, that previous to the death of a perſon, a light is ſometimes ſeen to proceed from the houſe, and purſue its

way to the church, precifely in the track that the funeral will afterwards follow. This is traditionally attributed to the fpecial prayer of St. David, that no one in his diocefe fhould die without this intimation of departure, which is called *Canwyll corph*, or the corpfe candle.

Language, &c. — The Welfh language has an undeniable claim to very high antiquity, as a dialect of the Hebrew, fpoken by the defcendants of Japhet: in its formation, as well as grammatical conftruction, it has a near refemblance to the original tongue; and is, perhaps, without exception, the moft primitive and uncorrupt living language in the weftern world. It abounds with original words, more efpecially technical terms, which other languages borrow from the Greek, or exprefs by circumlocution, and is faid to be peculiarly fitted for poetry. The orthoepy of the Welfh is very different from that of the Englifh. In the language of Cambria are forty-three letters; fixteen of which are radicals, expreffive of the primary founds; and the reft may be confidered as ferviles, becaufe ufed as inflexions or mutations of the former; for each of thefe there is an appropriate character. But the language is gradually getting into difufe, efpecially in the fouthern part of the principality. The gentry of the country are principally educated in England, and confequently few of them fpeak it, and many wifh for its extermination. The example of the higher claffes extends, and ere long the language and manners of Cambria may coalefce with thofe of the inhabitants to the eaft of the Severn. See grammar attached to Owen's Dictionary of the Welfh Language, which contains an ample critical differtation, &c. 2 vols. 4to. 1803.

Poetry was in high eftimation among the ancient Britons: Wales, as their place of refuge, was early the feat of the poetic mufe, and modern effufions of original genius evince that fhe has not deferted her favourite mountains. In no nation, except the Hebrew, was genealogy confidered of fo much importance, or carried to an equal extent, as in Wales. Family diftinction is purfued fo far, that perhaps it induces the Cambrian to think more highly of himfelf than is rational. Pride of anceftry was a delicate and effential point among the ancient Britons, and confequently they were more defirous of noble than of rich connections. So deeply was this principle rooted, that even the loweft claffes of the people carefully preferved the defcents of their families, and were in general able from memory not only to recite the names of their proximate progenitors, but to trace their various relations back through numerous generations.

Whoever reads the hiftory of the moft ancient inhabitants of this ifland, the Cambro Britons, will find innumerable inftances of the reverence which they paid to their poet-muficians, the bards, both of Pagan and Chriftian times; and fongs of very high antiquity have been preferved in the Welfh language, though not all the tunes to which they were fung. The harp, with which thefe fongs ufed to be accompanied, was in fuch general favour in Wales, as to be regarded among the poffeffions neceffary to conftitute a gentleman. (Leges Wallicæ.) The moft ancient Welfh poetry that is now intelligible was written about the year 1100, and fome of the tunes that are preferved in the late Mr. Morris's MS., which were tranfcribed from the mufic-book of William Penllin, the harper in queen Elizabeth's time, are fuppofed by Dr. Davies (In Præf. ad Gram. Brit.) to be coeval with the verfes to which they were fung, when he compofed his grammar and catalogue of ancient Cambro-Britifh fongs. Unluckily the notation, or tablature, in which thefe tunes have been written, is fo uncommon and difficult to reduce to modern characters, that though the gravity or acutenefs of the feveral notes can be afcertained, yet their lengths, or duration, cannot be eftablifhed with any degree of certainty, by any rule which we have been yet able to devife.

The northern annals abound with pompous accounts of the honours conferred on mufic by princes who were themfelves proficients in the art, and the Cambro-Britifh inftitutes, with laws and privileges in favour of its profeffors. As the firft mufician, or bard, was the eighth officer in dignity, at the court of the Welfh kings, and had a place in the royal hall next to the fteward of the houfhold, fo the refpect and dignity with which bards in general were treated about this time, in all the courts of Europe, were equal to thofe which Homer tells us their predeceffors Demodocus and Phemius enjoyed in Greece. Mufic was now a regal accomplifhment, as we find by all the ancient metrical romances and heroic narrations in the new-formed languages of the times; and to fing to the harp was neceffary to a *perfect prince* and *complete hero*.

The firft Greek muficians were gods; the fecond heroes; the third bards; the fourth beggars! During the early times of mufic, in every country, the wonder and affections of the people have been gained by *furprize;* but when muficians became numerous, and the art was regarded of eafier acquirement, they loft their favour, and from being feated at the tables of kings, and helped to the firft cut, they were reduced to the moft abject ftate, and ranked among rogues and vagabonds.

For more particular accounts of different parts of Wales, the reader is referred to the names of the twelve counties: *viz.* ANGLESEA, BRECKNOCKSHIRE, CAERNARVONSHIRE, CAERMARTHENSHIRE, CARDIGANSHIRE, DENBIGHSHIRE, FLINTSHIRE, GLAMORGANSHIRE, MERIONETHSHIRE, MONTGOMERYSHIRE, PEMBROKESHIRE, and RADNORSHIRE. —Hoare's Giraldus Cambrenfis, 2 vols. 4to. 1806. Beauties of England and Wales, vol. xvii., North Wales, by Rev. J. Evans, 1812. Ditto, vol. xviii., by Rev. T. Rees, 1815. Warrington's Hiftory of Wales, 2 vols. 8vo. 1788. Malkin's Scenery and Antiquities of South Wales, 2 vols. 8vo. 1807. Aikin's Journal of a Tour through North Wales, 12mo. 1797. Evans's Tour through North Wales, 8vo. 1802. Ditto through South Wales, 8vo. 1804.

Waterwheel

Machines actuated by the Force of Currents or Streams of Water.—Thefe are very numerous, but all may be reduced to two kinds.

Firft, thofe which are adapted to receive the impulfe of moving water; that is, water which has been put in motion in confequence of a defcent towards the earth previoufly to its operating on the machine, which muft be provided with parts proper to refift and take away fome of the motion of fuch water, and it will thereby receive motion which may be applied to produce fome mechanical effect. Of this kind are underfhot and horizontal water-wheels.

Secondly, thofe machines which are provided with fome kinds of buckets or veffels to contain water, the weight of which buckets, and the water they contain, is fupported by the machine, fo that the water cannot defcend towards the earth in confequence of its gravitation, without giving motion to the buckets or veffels which contain and fupport it. Of this kind is the over-fhot water-wheel, breaft-wheel, chain of buckets, and preffure-engine.

In either cafe, the motive force or power is the fame; *viz.* the gravitation and motion of fuch bodies or maffes of water as are found more elevated above the furface of the earth than the general level of the fea, or of fome other water in its neighbourhood; fuch water will defcend by the force of gravity until it joins the fea, or until it is fupported or held up by fome fixed obftacle.

The difference between the two kinds of machines is, that in the firft cafe the water is fuffered to defcend before it operates upon the machine, and in confequence of its gravitation, acquires motion with a velocity proportioned to the fpace through which it has defcended; and the office of the machine is to take from the moving water as much of its compounded weight and motion, or power, as it can obtain.

In the other cafe, the machine receives its motion and power at the fame time, when the water acquires it, by defcending; or, in other words, the machine moves with the water.

The word *power*, as ufed in practical mechanics, fignifies the exertion of ftrength, gravitation, impulfe, or preffure, fo as to produce motion; and a machine actuated by means of ftrength, gravitation, impulfe, or preffure, compounded with motion, is capable of producing an effect: and no effect is properly mechanical but what requires fuch a kind of power to produce it.

The mufcular power of animals, as likewife preffure, impact, gravity, electricity, &c. are looked upon as forces, or fources of motion; for it is an incontrovertible fact that bodies expofed to the free action of either of thefe are put in motion, or have the ftate of their motion changed. All forces, however various, can be meafured by the effects they produce in like circumftances; whether the effects be creating, accelerating, retarding, or deflecting motions: the effect of fome general and commonly obferved force is taken as unity.

The moft proper meafure of power is the act of raifing fome weight with fome velocity of motion; that is, the overcoming of the gravitating force of a weight in fuch degree as to produce motion in oppofition to gravity. In confidering the quantum, the weight or mafs of matter operated upon muft be one quantity, and the velocity of the motion communicated is the other; the mechanical power is

the compound of both. We can only meafure the weight of any body or mafs of matter by its relation to fome other weight with which we are acquainted; hence we fay, the weight is equal to fo many pounds, or fo many cubic feet of water. In like manner, we meafure the velocity or intenfity of the motion, by ftating the height or perpendicular diftance from the earth, (meafured by relation to fome known diftance, as a foot or a yard,) through which height the weight is raifed in fome known fpace of time, as a fecond or a minute.

For inftance, 528 cubic feet of water is a known weight or mafs of water: let a machine operate upon this, and raife it upwards, through the fpace of one foot in the time of one minute; then $528 \times 1 \times 1 = 528$ is the number which reprefents the power which the machine exerts. Suppofe another machine to operate on 132 cubic feet of water, and raife it four feet in one minute, then ufing the fame meafures to determine the quantities of weight, height, and time, we fay $132 \times 4 \times 1 = 528$; hence thefe two machines are equal in the power which they exert; for in all cafes the weight raifed is to be multiplied by the height to which it can be raifed in a given time, and the product is the meafure of the power expended in raifing it; confequently, all thofe powers are equal whofe products made, by fuch multiplication, are equal; for example, take two powers, if one can in any given time raife twice the weight to the fame height, or the fame weight to twice the height, in the fame time that the other power can, the firft power is double the fecond; or, if one power can raife half the weight to double the height, or double the weight to half the height, in the fame time that another can, thofe two powers are equal: but note, all this is to be underftood only in cafes of flow or equable motion of the body raifed, for in quick, accelerated, or retarded motions, the *vis inertiæ* of the matter moved will make a variation.

The machines actuated by the impulfe of flowing water are, the underfhot water-wheel, horizontal wheels, and Dr. Barker's mill. It is a common expreffion to call all wheels in which the water runs or fhoots under the wheel, underfhot; but in this place we fhall only fpeak of

Underfhot Water-Wheels, acting by the Impulfe of flowing Water.—Thefe are the moft ancient and original forms of water-machines, although if they had been invented from the refult of reafoning, fuch as we have given, they would have been the laft, becaufe their manner of action is lefs obvious; but this was not the cafe. The firft machines were wheels placed in a river or running ftream, and provided with vanes or wings on the circumference, called floats; the floats at the lower part of the wheel, dipped into the ftream to intercept the water. When the plane of the floats became perpendicular to the direction of the current, or nearly fo, they would refift or oppofe the motion of the water, and the wheel would obtain motion from it in proportion to the quantity of motion, its floats abftracted from the water of the ftream. The power thus obtained would be found to be only a fmall proportion of the power of the ftream, becaufe the water would eafily efcape fideways from the floats, particularly if it were attempted to take away any confiderable fhare of the velocity of the water, by refifting or loading the wheel, fo as to make it move flowly. Hence it became an obvious improvement to contract the river to the exact fize of the float-boards of the wheel, or to make a clofe channel in which the wheel exactly fits. The next improvement would be to intercept the river or ftream of water by a dam, or obftacle, in order to make it pen up, or accumulate, till it had rifen to the greateft height which could be obtained, and to let the water out of the dam or refervoir into the channel or wheel-courfe, through a vertical aperture or door, level with the bottom of the wheel-courfe; in this way, the water would be urged by the preffure of the water in the dam, and would rufh out from the aperture in a ftream or fpout, with a velocity proportioned to the perpendicular preffure, and would ftrike the float-boards of the wheel fo as to urge them forwards. Such is the form of the underfhot wheels ftill generally employed in France and on the continent; but in England they have been long fuperfeded by more effectual applications of the power of the water, and it is very rarely we meet with an underfhot wheel acting by the impulfe of the water. They are called ground-fhot wheels, becaufe the water runs or fhoots along the ground or floor of the channels in which the wheels work.

It was firft proved by Mr. Smeaton, in 1754, that only a portion of the power of any fall of water could be obtained by means of an underfhot wheel; for M. Belidor had not long before ftated the underfhot wheel as the beft mode of applying a fall of water. It was one of the continual occupations of Mr. Smeaton, during forty years, to improve the old water-mills, by fubftituting breaft-wheels for underfhot; and the advantages were uniformly fo great, that thefe mills were copied by others, until fcarcely any of the original conftruction remained. We do not mean that Mr. Smeaton invented the breaft-wheel, for it is defcribed by Leopold; but he firft inveftigated its comparative advantages.

It is from this circumftance that we find, in all the mechanical writings of foreign authors, much more mathematical inveftigation relative to the underfhot water-wheels than the importance of the fubject deferves, and we fhall difmifs it more briefly.

The excellent paper by Mr. Smeaton, in the Philofophical Tranfactions for 1759, contains a numerous lift of experiments moft judicioufly contrived by him, and executed with the accuracy and attention to the moft important circumftances which are to be obferved in all that gentleman's performances.

Mr. Smeaton's rules were originally deduced from experiments made on working models, which are the beft means of obtaining the outlines in mechanical enquiries; but in every cafe it is neceffary to diftinguifh the circumftances in which a model differs from a machine at large, otherwife a model is more apt to lead from truth than towards it; and we muft not, without great caution, transfer the refults of fuch experiments to large works. But we may fafely transfer the laws of variation, which refult from a variation of circumftances, although we muft not adopt the abfolute quantities of the variations themfelves. Mr. Smeaton was fully aware of the limitations to which conclufions drawn from experiments on models are fubject, and has made the applications with his ufual fagacity. The beft ftructure of machines cannot be fully afcertained but by making trials with them, when made of their proper fize.

Mr. Smeaton's Principles for Underfhot Wheels.—In comparing the effect produced by water-wheels with the powers producing them; or, in other words, to know what part of the original power is neceffarily loft in the application, we muft previoufly know how much of the power is fpent in overcoming the friction of the machinery, and the refiftance of the air; alfo, what is the real velocity of the water at the inftant it ftrikes the wheel; and the real quantity of water expended in a given time.

The velocity Mr. Smeaton meafured in a moft fatisfactory manner in every experiment, by applying a cord and weight to the axle of the wheel, not to wind up the weight by the

motion of the wheel, but that the weight by deſcending ſhould turn the wheel. He applied ſo much weight as would make the wheel turn, and make its floats move with the velocity which he deſired or expected the effluent water to have; and this weight he adjuſted until he found, by repeated trials, that the wheel moved juſt at the ſame rate, whether the water was ſuffered to flow and ſtrike its floats, or whether the water was ſtopped, which proved that the floats of the wheel moved with preciſely the ſame velocity as the effluent water; then by meaſuring the circumference of the wheel, and counting the number of turns it made in a minute, he obtained the meaſure of the velocity.

From the velocity of the water at the inſtant that it ſtrikes the wheel, the height of head productive of ſuch velocity can be deduced from acknowledged and experimented principles of hydroſtatics; ſo that by multiplying the quantity or weight of water really expended in a given time by the height of a head ſo obtained, which muſt be conſidered as the effective height from which that weight of water had deſcended in that given time, we ſhall have a product equal to the original power of the water, and clear of all uncertainty that would ariſe from the friction of the water in paſſing ſmall apertures, and from all doubts ariſing from the different meaſure of ſpouting waters, aſſigned by different authors.

On the other hand, the ſum of the weights raiſed by the action of this water, and of the weight required to overcome the friction and reſiſtance of the machine, multiplied by the height to which the weight can be raiſed in the time given, the product will be equal to the effect of that power; and the proportion of the two products will be the proportion of the power to the effect: ſo that by loading the wheel with different weights ſucceſſively, we ſhall be able to determine at what particular load and velocity of the wheel the effect is a maximum.

From experiments conducted in this manner, Mr. Smeaton ſettled the following maxims:

Maxim 1. That the virtual or effective head of water, and conſequently its effluent velocity being the ſame, the mechanical effect produced by a wheel actuated by this water will be nearly in proportion to the quantity of water expended.

Note. The virtual or effective head of any water which is moving with a certain velocity, is that height from which a heavy body muſt fall in order to acquire the ſame velocity.

The height of the virtual head, therefore, may be eaſily determined from the velocity of the water; for the heights are as the ſquare of the velocities; and the velocities, conſequently, as the ſquare roots of the heights. Mr. Smeaton obſerved the velocity of the effluent water in all his experiments, and thence calculated the virtual head; he ſtates that the virtual head bears no proportion to the real head or depth of water; but that when either the aperture is greater, or when the velocity of the water iſſuing therefrom leſs, they approach nearer to a coincidence; and conſequently, in the large openings of mills and ſluices, where great quantities of water are diſcharged from moderate heads, the actual head of water, and the virtual head, as determined by theory from the velocity, will nearly agree.

For example of the application of his firſt maxim. Suppoſe a mill driven by a fall of water, whoſe virtual head is 5 feet, and which diſcharged 550 cubic feet of water *per* minute; and that it is capable of grinding four buſhels of wheat in an hour. Now another mill, having the ſame virtual head, but which diſcharges 1100 cubic feet of water *per* minute, will grind eight buſhels of corn in an hour.

Maxim 2. That the expence of water being the ſame, the effect produced by an underſhot wheel will be nearly in proportion to the height of the virtual or effective head. This is proved in the preceding example.

Maxim 3. That the quantity of water expended being the ſame, the effect will be nearly as the ſquare of the velocity of the water; that is, if a mill driven by a certain quantity of water, moving with the velocity of 18 feet *per* ſecond, is capable of grinding 4 buſhels of corn in an hour, another mill, driven by the ſame quantity of water, but moving with the velocity of $22\frac{1}{2}$ feet *per* ſecond, will grind nearly 7 buſhels of corn in an hour; becauſe the ſquare of 18 is 324, and the ſquare of $22\frac{1}{2}$ is $506\frac{1}{4}$. Now ſay, as 324 is to 4 buſhels, ſo is $500\frac{1}{4}$ to $6\frac{1}{8}$ buſhels; that is, as 4 to $6\frac{1}{8}$.

Maxim 4. The aperture through which the water iſſues being the ſame, the effect will be nearly as the cube of the velocity of the water iſſuing; that is, if a mill driven by water ruſhing through a certain aperture with the velocity of 18 feet *per* ſecond will grind 4 buſhels of corn in an hour, another mill, driven by water moving through the ſame aperture, but with the velocity of $22\frac{1}{2}$ feet *per* ſecond, will grind 51 buſhels; for the cube of 18 is 5832, and the cube of $22\frac{1}{2}$ is $11390\frac{3}{4}$; then, as 5832 is to 4, ſo is $11390\frac{3}{4}$ to $7\frac{3}{4}$.

Maxim 5. The proportions between the power of the water expended, and the effect produced by the wheel, was 3 to 1. Upon comparing ſeveral experiments, Mr. Smeaton fixed the proportions between them for large works; that is, if the weight of the water which is expended in any given time be multiplied by the height of the fall, and if the weight raiſed be alſo multiplied by the height through which it is raiſed, the firſt of theſe two products will be three times that of the ſecond.

Maxim 6. The beſt general proportions of velocities between the water and the floats of the wheels will be that of 5 to 2; for inſtance, if the water when it ſtrikes the wheel moves with a velocity of eighteen feet *per* ſecond, the wheel muſt be ſo loaded that its float-boards will move with a velocity of 7.2 feet *per* ſecond, and the wheel will then derive the greateſt power from the water, becauſe as 5 to 18, ſo is 2 to 7.2.

Maxim 7. There is no certain ratio between the load that the wheel will carry when producing its maximum of effect, and the load that will totally ſtop it; but it approaches neareſt to the ratio of 4 to 3, whenever the power exerted by the wheel is greateſt, whether it ariſes from an increaſe of the velocity, or from an increaſed quantity of water; and this proportion ſeems to be the moſt applicable to large works. But when we know the effect a wheel ought to produce, and the velocity it ought to move with whilſt producing that effect, the exact knowledge of the greateſt load it will bear is of very little conſequence in practice.

Maxim 8. The load that the wheel ought to have, in order to work to the moſt advantage, can be always aſſigned thus: aſcertain the power of the whole body of water, by multiplying the weight of the water expended in a minute by the height of the fall, take one-third of the product, and it gives the effect of power which the wheel ought to produce: to find the load, we muſt divide this product by the velocity which the wheel ſhould have, and that, as we have before ſettled, ſhould be two-fifths of the velocity with which the water moves when it ſtrikes the wheel.

The wheel muſt not be placed in an open river to be actuated by the natural current, in which caſe, after it has communicated its impulſe to the float, it has room on all ſides to eſcape: this is the ſuppoſititious caſe on which moſt mathematicians have proceeded; but in all theſe experi-

ments, the wheel is placed in a conduit or race, to which the float-boards are exactly adapted, and the water cannot otherwise escape than by moving along with the wheel. It is observable in a wheel working in this manner, that as soon as the water meets the float, it receives a sudden check, and rises up against the float, like a wave against a fixed object, insomuch that when the sheet of water is not a quarter of an inch thick before it meets the float, this sheet will act upon the whole surface of a float, whose height is three inches; and consequently, where the float is no higher than the thickness of the sheet of water, as theory also supposes, a great part of the force would have been lost by the water dashing over the float.

The wheel which Mr. Smeaton used had originally twenty-four floats, and was afterwards reduced to twelve, which caused a diminution in the effect, on account of a greater quantity of water escaping between the floats and the floor of the channel in which it moved; but a circular sweep being adapted thereto, of such a length, that one float entered the curve before the preceding one quitted it, the effect came so near to the former as not to give hopes of advancing it, by increasing the number of floats beyond twenty-four in this particular wheel.

Mr. Smeaton observes that, in many of the experiments, the results were by different ratios than those which his maxims supposed; but as the deviations were never very considerable, the greatest being about one-eighth of the quantities in question, and as it is not practicable to make experiments of so compound a nature with absolute precision, he supposes, that the lesser powers are attended with some friction or work under some disadvantages, which have not been duly accounted for; and, therefore, he concludes that these maxims will hold very nearly, when applied to works in large.

Application of these Principles to Practice.—The first thing to be done in a situation where an undershot wheel is intended to be fixed, is to consider whether the water can run off clear from the wheel, so as to have no back water to impede its motion; and whether the fall which can be obtained by constructing a proper dam to pen up the water and sluice for it to pass through, will cause it to strike the float-boards of the wheel with a sufficient velocity to impel them forcibly forwards; and also, whether the quantity of the supply will be sufficient to keep a wheel at work for a certain number of hours each day.

When we have ascertained the height of the fall of water, that is, the height of the surface above the centre of the opening of the sluice, we must find what will be the continual velocity of the water issuing out from such opening.

In some cases, we have the velocity of the water given when it issues from the opening of the sluice, and we then require to know what height of column will produce that velocity. These two things we may find by a single rule, and an easy arithmetical operation, which is as follows:

1st. The perpendicular height of the fall of water being given in feet and decimals of feet, the velocity that the water will acquire *per* second, expressed in feet and decimals, may be found by the following rule:

Multiply the constant number 64.2882 by the given height, and the square root of the product is the velocity required.

Example 1.—If the height is two feet, the velocity will be found 11.34 feet *per* second.

Example 2.—If the height is 16,0913 feet, the velocity will be 32,1826 feet *per* second.

Example 3.—If the height is fifty feet, the velocity will be 56,68 feet *per* second.

Note. The velocities thus obtained will be only the theoretic velocity, that is, the velocity any body would acquire by falling through such height *in vacuo*, the velocity in reality will be less, generally six or seven-tenths.

The uniform velocity of a fluid being given, expressed in feet and decimals of feet *per* second, the height of the column or fall to produce such a velocity may be found by the following rule:

Multiply the given velocity into itself, and divide the product by 64,2882; the quotient will be the height required, expressed in feet and decimals.

Example 1.—If the velocity given is three feet *per* second, the height will be 0.139 of a foot.

Example 2.—If the velocity given is 32,1826 feet *per* second, the height will be found 16,0913 feet.

Example 3.—Let the velocity be 100 feet *per* second, the height will be 155,649 feet.

The knowledge of the foregoing particulars is absolutely necessary for constructing an undershot water-wheel; but the most advantageous method of setting it to work, and to find out the utmost it could perform, would be very difficult, if we were not furnished with the maximum which Mr. Smeaton settled, by shewing, that an undershot water-wheel will act to the greatest advantage, when the velocity of its float-boards is equal to two-fifths or four-tenth parts of that of the water which gives it motion.

To illustrate this, let us consider a wheel equally balanced on all sides, and turning freely round upon its pivots, its circumference would soon move as fast as the current it was placed in. Suppose the water to move at the rate of three feet in a second, the circumference of the wheel would pass through three feet in a second. In this case, the wheel performs no work, and the effect produced is nothing.

Now in attempting to apply the power of this wheel to turn any kind of machinery, suppose the work to be so proportioned, that the resistance would cause the wheel to stand still and stop the water, or make it run over the floats, in consequence of its not having sufficient force to carry the float-boards along with it. In this case also, there being no motion, there could be no mechanical effect produced; but if the resistance be diminished by degrees, the wheel would begin to partake of the motion of the current of water, and being loaded, would produce a mechanical effect proportioned to the load and velocity. The wheel would increase in its velocity in proportion as the resistance was diminished, and the mechanical effect would increase also until a certain point when the wheel moved so fast, that the water would not strike the float-boards quick enough to produce the greatest effect: this is found to be as before mentioned, when the floats move four-tenths as fast as the water, because then six-tenths of the water is employed in driving the wheel with a force proportional to the square of its velocity.

If we multiply the surface or area of the opening by the height of the column, we shall ascertain the body or column of water which should press against that float-board, which is immediately under the wheel, supposing it has no motion; but it will be found, that a small proportion of the weight of the original column hung on the opposite side of the wheel, would arrest its motion entirely; but when we would have it to move with a proper velocity, that is, two-fifths of that velocity with which the water moves, $\frac{133}{1000}$ of the weight of the original column, is the weight which the wheel would raise with four-tenths of the velocity that the water moves with, and the power which the wheel would exert on the machinery to grind corn, lift hammers, raise

water, &c. is $\frac{133}{1000}$ of the weight of the water multiplied by $\frac{4}{10}$ of its velocity.

Thus it appears that an underſhot water-wheel, conſtructed after the foregoing manner, would only raiſe one-third part of the water expended to the ſame height, as the original head or level. This is the utmoſt that can be expected, though often leſs is done; becauſe here we ſuppoſe every part exactly performed, and the water applied to the wheel in the beſt manner; therefore, as we cannot come up to the maximum, we muſt come as near it as we can by loſing the leaſt poſſible of the power's impulſe.

It is no advantage to have a very great number of float-boards round the wheel, becauſe when they are ſtruck by the water, as applied in the beſt manner poſſible, the ſum of the impulſes exerted on the different floats, will but be equal to the impulſe made againſt one float-board ſtruck by all the water iſſuing from the ſluice at right angles to its ſurface. But as this float-board muſt move forward, there muſt be a ſucceſſion of float-boards to receive the impulſe of the water, and ſince they cannot receive it at right angles, there will be ſome loſs of impulſe in that ſucceſſion. Beſides when the firſt float-board is ſo far paſt the perpendicular, as to have the action of the water intercepted by the ſucceeding one, it is checked by the back water through which it muſt paſs in riſing out of the water, and thereby be ſo far retarded as to take from the full effect of the impulſe on the following float. Indeed if all the water could run off immediately after having performed its office, this would not happen; but it can ſeldom be effected in underſhot-mills, eſpecially thoſe built upon rivers. All the remedy in ſuch caſe is, (when the diameter of the wheel is ſettled) to fix juſt ſuch a number of floats upon it, that each one, after it has received the full impulſe of the water, may come out of the water as ſoon as poſſible, that another ſucceeding float may be brought to receive the impulſe, otherwiſe the wheel would remain a moment without any impulſe.

In the article MILL we have given a table for the dimenſions and proportions for underſhot wheels, which was calculated by Mr. Ferguſon. Dr. Brewſter, in his new edition of Mr. Ferguſon's works, has given an improved table, which is calculated upon the following principles.

It is evident that the water-wheel muſt always move with leſs velocity than the water, even when there is no work to be performed; for a part of the impelling power is neceſſarily ſpent in overcoming the *inertia* of the wheel itſelf; and if the wheel has little or no velocity, it is equally manifeſt that it will produce a very ſmall effect.

There is conſequently a certain proportion between the velocity of the water and the wheel, when the effect is a maximum. Mr. Smeaton has ſhewn the greateſt effect is produced when the velocity of the wheel is between one-third and one-half, but the maximum is much nearer to one-half than one-third. He obſerves alſo that one-half would be the true maximum, if nothing were loſt by the reſiſtance of the air, the ſcattering of the water carried up by the wheel, and thrown off by the centrifugal force, and the leakages of the water between the floats and the water-courſe, all which tend to produce a greater diminution of the effect at that velocity, which would be the maximum if theſe loſſes did not take place, than they do when the motion is a little ſlower. The great hydraulic machine at Marly, the wheels of which are underſhot, was found to produce a maximum effect when the velocity of the wheel was two-fifths that of the current. Hence Dr. Brewſter concludes that in theory the velocity of the wheel is one-half that of the current, and that in practice it is never more than three-eighths of the ſtream's velocity, when the effect is a maximum.

Dr. Brewſter's Table of underſhot Water-Wheels, in which the velocity of the wheel is three-ſevenths of the velocity of the water, and the effects of friction on the velocity of the ſtream are reduced to computation. The wheel is ſuppoſed to be fifteen feet diameter.

Height of the Fall of Water.	Velocity of the Water *per* Second, Friction being conſidered.	Velocity of the Wheel *per* Second being three-ſevenths that of the Water.	Revolutions of the Wheel *per* Minute, its Diameter being fifteen Feet.
Feet.	Feet and Decimals.	Feet and Decimals.	Revolutions and Decimals.
1	7.62	3.27	4.16
2	10.77	4.62	5.88
3	13.20	5.66	7.20
4	15.24	6.53	8.32
5	17.04	7.30	9.28
6	18.67	8.00	10.19
7	20.15	8.64	10.99
8	21.56	9.24	11.76
9	22.86	9.80	12.47
10	24.10	10.33	13.15
11	25.27	10.83	13.79
12	26.40	11.31	14.40
13	27.47	11.77	14.99
14	28.51	12.22	15.56
15	29.52	12.65	16.13
16	30.48	13.06	16.63
17	31.42	13.46	17.14
18	32.33	13.86	17.65
19	33.22	14.24	18.13
20	34.17	14.64	18.64

Another Manner of applying Water to an underſhot Wheel.—This was propoſed by M. Fabre as the reſult of much mathematical inveſtigation, and has been ſo frequently recommended by authors of eminence, that we ſhall give a ſhort deſcription without entering into all his rules for the proportions. The principal difference in this wheel from that in common uſe is, that the water is made to run down a rapid ſlope or inclined plane, in order to ſtrike the floats of the wheel, inſtead of iſſuing from an aperture or ſluice ſituated beneath the ſurface of the water in the reſervoir. A mill is uſually ſituated at a diſtance from the river, with a canal or water-courſe to conduct the water to the mill; as it is of the higheſt importance to have the height of the fall as great as poſſible, the bottom of the canal or water-courſe, which conducts the water from the river to the mill, ſhould have a very ſmall declivity; for the height of the water-fall at the mill will diminiſh in proportion as the declivity of the canal is increaſed: it will be ſufficient to make it ſlope about one inch in 200 yards, taking care to make the declivity about half an inch in the firſt 48 yards, in order that the water may have a velocity ſufficient to prevent it from flowing back into the river.

When the water is thus brought to the channel in which the wheel is placed, the water is recommended to be conducted down a ſlope or inclined plane, making an angle of $64\frac{1}{2}$ degrees with the horizon; that is, in a perpendicular of ten feet, the ſlope ſhould deviate from it $4\frac{3}{4}$ feet: at the bottom of this ſlope the water is to be again conducted horizontally, and then to ſtrike the float-boards of the

wheel. To render the fall of the water eafy, the flope is to be rounded off by a convexity at top and a concavity at bottom, to lead the water from the horizontal to the flope, and again from the flope without abruptnefs. It is fuppofed that the water, in running down this inclined plane, will acquire the fame velocity as if it had fallen perpendicularly through a height equal to the perpendicular height of the flope.

The diftance through which the water runs horizontally, from the foot of the flope before it acts upon the wheel, fhould not be lefs than two or three feet, in order that the different portions of the fluid may have obtained an horizontal direction; but if this horizontal diftance be much larger, the velocity of the ftream would be diminifhed by its friction on the bottom and fides of the water-courfe. That lefs water may efcape between float-boards and the bottom of the courfe, it fhould be formed into the arch of a circle concentric with the wheel, which fweep fhould be prolonged, fo as to fupport the water as long as it can act upon the float-boards; beyond this fweep fhould be a ftep or fall of not much lefs than nine inches with a flope of about 45 degrees, that the water having fpent the greater part of its force in impelling the float-boards, may not accumulate below the wheel and retard its motion. After this ftep the courfe of difcharge, or tail water-courfe to run off the water from the wheel, fhould be floored with wood or mafonry about 16 yards long, having an inch of declivity in every two yards.

The canal which conducts the water from the courfe of difcharge to join the river again, fhould flope about four inches in the firft 200 yards, and three inches in the fecond 200 yards, and fo decreafing gradually till it terminates in the river. But if the river to which the water is conveyed, fhould be fubject to be fwollen by the rains, fo as to force the water back upon the wheel, the canal muft have a greater declivity, in order to prevent this from taking place. Hence it will be evident, that very accurate levelling is neceffary for the proper formation of the mill-courfe. The tail water-courfe ought always to have a very confiderable breadth, which fhould be greater than that of the wheel-race, or part in which the wheel acts, that the water having room to fpread may have lefs depth. The fection of the fluid at the point where it ftrikes the wheel fhould be rectangular, the breadth of the ftream having a determinate relation to its depth. If there is a great ftream of water, the breadth fhould be triple the depth; if there is a moderate quantity, the breadth fhould be double the depth; and if there is very little water, the breadth and the depth fhould be equal. The depth of the water here alluded to is its natural depth, or that which it would have, if it did not meet the float-boards. The effective depth is generally two and a half times the natural depth, and is occafioned by the impulfe of the water on the float-boards, which forces it to fwell, and increafes its action upon the wheel.

As it is of great confequence that none of the water fhould efcape, either below the float-boards or at their fides, without contributing to turn the wheel. the breadth of the float-boards fhould be wider than the fheet of water which ftrikes them. The diameter of the water-wheel fhould be as great as poffible, unlefs fome particular circumftances in the conftruction prevent it; but ought never to be lefs than feven times the natural depth of the ftream or thicknefs of the fheet of water, where it meets the float-boards. The wheel will move irregularly, fometimes quick and fometimes flow, according to the pofition of the floats with refpect to the ftream; unlefs the number of float-boards is confiderable, the wheel muft have fo many floats, that two floats will at leaft be always in the circular fweep at the bottom of the wheel; but in order to remove any inequality of motion in the wheel, and prevent the water from efcaping beneath the tips of the float-boards, it fhould have as many float-boards as poffible, without loading it, or weakening the rim on which they are placed. The float-boards fhould not be perpendicular to the rim, or, in other words, a continuation of the radius, but fhould be inclined to the radius; the water will thus heap upon the float-boards, and act not only by its impulfe, but alfo by its weight. When the velocity of the ftream is eleven feet *per* fecond, or above this, the inclination fhould never be lefs than thirty degrees; or when this velocity is lefs, the inclination fhould diminifh in proportion; fo that when it is four feet, or under, the inclination fhould be nothing, that is, the float-boards fhould point to the centre of the wheel.

It is a ftrong practical objection to this manner of applying the water to the wheel, that when the water of the river finks in dry weather from a deficiency of water, it would not run over the top of the fall, and the mill could not work at all even if it funk only ten or twelve inches: in like manner, when the water rifes in floods, the water at the top of the fall would become fo deep, as to require fome fhuttle to prevent it from inundating the wheels, at the fame time that the ftagnant water in the mill-race would prevent the wheel from working. Almoft all rivers are fubject to floods, and often they rife and fall, three, four, fix, and eight feet above their ordinary level in fair weather; now the water moftly rifes at the tail or difcharge of the water as much as the head, and the wheel-race will therefore be full of ftagnant water, which is called tail-water, and obftructs the motion of the wheel.

In a ground-fhot wheel, where the water iffues from a fhuttle on a level with the bottom of the wheel-race, it can always work in dry feafons, as long as the river contains any water, although the power diminifhes almoft to nothing, when the water finks low, and will not rufh out with force from the fhuttle. In floods of water, this wheel has a greater advantage, becaufe the depth of head which urges the flowing water is increafed when the water is high, and this makes it drive the tail-water forcibly out of the wheel-race, and enable the wheel to work, when a wheel with an inclined fall would infallibly be ftopped.

Breaft-wheels and overfhot-wheels, properly conftructed, have ftill greater advantages, in clearing themfelves from tail-water, and this is a very important object.

Floating-Mill with underfhot Wheels.—A large floating water-mill, to be worked by the tides or currents, was ftationed fome years ago in the river Thames, between London and Blackfriars bridge, by permiffion of the Board of Navigation. Such permiffion having been granted with the view of reducing, if poffible, the price of flour in the metropolis, and contributing to a conftant fupply of that neceffary article of fubfiftence. The fimplicity of this invention renders a long defcription fuperfluous, as it confifts in merely applying the force of two large underfhot water-wheels on each fide of a barge, or any other veffel calculated to contain the interior part of the machinery; the float-boards are difpofed in a proper manner to be acted on by the tide or current, fo as to give the wheels a rotatory motion, and by connecting them with proper machinery, to anfwer the purpofes for which the mill is intended.

Any fhip, brig, floop, or other veffel, may be ufed for this purpofe, provided it is of fufficient fize to accommodate the works to be erected, yet in point of expence it will be better to employ fuch as are rendered unfit for fea-fervice.

When it is intended that the ſhip or mill ſhould be ſtationary, it muſt be anchored, moored, or otherwiſe made faſt, ſo as to ſwing with the tide when neceſſary; but the mill may be worked while the veſſel in which it is erected is ſailing, when wind and other circumſtances permit.

The number and ſize of the water-wheels to be uſed may be varied, according to the ſize of the ſhip or veſſel, or to the ſtrength of the tide or current, and the power required; and the wheels may be conſtructed as in common underſhot mills, or with folding-floats, for the more readily freeing them from the water: two wheels are to be placed vertically, on an horizontal axis, of ſuch length, that, the axis being placed acroſs the ſhip or veſſel, one wheel may run on each ſide of it on the ſame axis.

A mill conſtructed in the manner above deſcribed may be moved by the ſtrength of from two to ſix large water-wheels, or ſuch other number as the ſhip or veſſel will accommodate. Theſe water-wheels may dip into the water from three to four, or more feet deep; they ſhould be ſo connected together as to be eaſily engaged with and diſengaged from each other, ſo that during the weak part of the tide they may all be made to act on one pair of mill-ſtones, if neceſſary; and as the ſtrength of the tide increaſes, more ſtones or other machinery may be put in motion, ſo as at all times to do buſineſs in proportion thereto.

In a mill of this kind the water-wheels do not admit of having water-courſes, or any equivalent contrivances, to conduct the water to the wheels, as in other underſhot wheels; but the float-boards muſt be large enough to receive the power required from merely dipping into the current of the tide-water.

The veſſel of the mill in the Thames is the hull of an old ſhip of two or three hundred tons burthen, which being moored in the river by chains, ſo that it can ſwing round when the tide changes, the wheels will always turn the ſame way round; one water-wheel is fixed on each ſide of the veſſel, a long iron axis being common to both; the extreme ends of the axis are ſupported in a frame-work of timber, and another very ſtrong frame of timber is fixed outſide of the wheels at the level of the water, which floats in the water, and is only attached to the mill by chains; this is to protect the wheels from injury, by veſſels which paſs and repaſs. Each water-wheel is 18 feet diameter, and 14 feet broad; the float-boards are each 3 feet deep, and are about ſixteen in number, affixed on the circumference of cart iron-wheels, or circles, which are 12 feet diameter, there are three of theſe circles for each wheel; hence we find each float-board expoſes a ſurface of 42 ſquare feet to the action of the current, and if we ſuppoſe each wheel to have two floats in action at the ſame time, the power of the mill will be derived from 168 ſquare feet acted upon by the water, which ſeldom exceeds a velocity of four miles *per* hour, or 352 feet *per* minute.

The iron axis of the water-wheels is a hollow tube of nine inches diameter outſide, and five inches within, made in four lengths of 12 feet each, properly joined together, and extending acroſs the veſſel from one wheel to the other. On the middle of this axis a large wheel of 11 feet diameter is fixed, and ſurrounded by a brake or gripe like that uſed in a wind-mill, the uſe of which is to ſtop the mill when it requires repairing. Near to this brake-wheel is a large bevilled cog-wheel 13 feet diameter, with 89 cogs, which gives motion to a bevilled pinion two feet eight inches diameter, with eighteen cogs fixed on the top of a vertical axis. On this axis is alſo a large horizontal ſpur-wheel 12 feet diameter, with 201 cogs, which gives motion to pinions of one foot diameter, and 17 cogs fixed on the ſpindles of the mill-ſtones. There are four pair of mill-ſtones, two pair of 4½ feet and two pair of 3½ feet diameter, and the mill alſo works a dreſſing-machine for the flour. The mill-ſtones make 57½ revolutions for one revolution of the water-wheels, which move very ſlow, ſcarcely two turns *per* minute, in the moſt favourable periods of the tide. The circumference of each taken through the middle of the float-boards is 47 feet; hence the float-boards move about 94 feet *per* minute, when the mill-ſtones make their proper number of revolutions to grind with the greateſt effect.

It was found that on a flood-tide, this mill would drive two pair of 3½ feet mill-ſtones, and a flour dreſſing-machine, but on the ebb-tide only one pair of 4-feet ſtones and the machine; thus it is only the performance of a ſmall mill, although the wheels are of large dimenſions, and it would require enormous wheels to make an effective floating mill in the river Thames.

This machine is now removed from the river, becauſe it was found to do ſo much injury to the veſſels which continually ran againſt its floating frame, and the repairs of the damages frequently done to the mill by ice and the craft took away all the advantages of the mill.

Underſhot Wheels with oblique Floats.—Attempts have been made to conſtruct water-wheels for tide-rivers which receive the impulſe obliquely, like the ſails of a common wind-mill. This would in many ſituations be a great advantage. A very ſlow but deep river could in this manner be made to drive mills; and although much power would be loſt by the obliquity of the impulſe, the remainder might be very great. Dr. Robinſon ſpeaks of a wheel of this kind which was very powerful; it was a long cylindrical frame, having a plate ſtanding out from it about a foot broad, and ſurrounding it with a very oblique ſpiral like a cork-ſcrew. This was immerſed about one-fourth of its diameter (which was nearly 12 feet), having its axis in the direction of the ſtream. By the work which it was performing, it ſeemed more powerful than a common wheel which occupied the ſame breadth of the river. Its length was not leſs than 20 feet; had it been twice as much it would have been nearly redoubled in its power without occupying more of the water-way. It is probable ſuch a ſpiral continued quite to the axis, and moving in a hollow canal wholly filled by the ſtream, might be a very advantageous way of employing a deep and ſlow current.

In the Tranſactions of the Society of Arts, vol. xix. a water-wheel is deſcribed, in which the float-boards are placed obliquely to the axis of the water-wheel at about an angle of 40 degrees, being fixed to the rim in pairs, which are inclined equally to the axis of the wheel, but in oppoſite directions to each other; ſo that the two float-boards of each pair point towards each other in an angle of about 80 degrees, and if the pair of floats were continued they would meet in the middle of the breadth of the wheel. The water is made to ſtrike the floats within this angle, and in conſequence all the water which is emitted by the ſluice and ſtrikes upon the oblique floats will be reflected from the ſides or ends of the two pair of float-boards towards the vertex of the angle, which they make; but the pair of floats do not touch each other, ſo that the vertex of the angle is open; but to prevent the water paſſing freely through the open angle, one of the float-boards is made to extend far beyond the vertex, or point, where they would interſect, and the other is made to fall ſhort of it, nevertheleſs the water would certainly paſs through the opening. It is ſtated, that the motion of the ordinary wheel with parallel floats is greatly retarded by the reſiſtance which they experience in riſing up or quitting the tail-water of the ſtream, from the

preffure of the atmofphere on their upper furface before the air gets admiffion beneath the floats ; but in Befant's wheel this refiftance is greatly diminifhed, as the floats emerge from the ftream in an oblique direction. The water-wheel is conftructed in the form of a hollow drum, fo as to refift the admiffion of the water. Although this wheel is much heavier than thofe of the common conftruction, yet it revolves more eafily upon its axis, as the ftream has a tendency to make it float. We cannot recommend this wheel, but on the contrary think it one of the worft forms, as it tends to increafe that lofs which arifes in all underfhot-wheels from the change of figure which the water muft undergo when it ftrikes the float, and we fhould not have mentioned it, but that it has been fo frequently copied and recommended by different authors.

Horizontal Water-wheels actuated by the Impulfe of Water.—Thefe have been confiderably in ufe on the continent, and deferve our notice from the fimplicity of their conftruction. The wheel is conftructed in the fame manner as an underfhot-wheel, having float-boards fixed round its circumference in the form of radii ; it is mounted on a vertical axis, the upper end of which is fixed to the fpindle of the mill-ftone, if the mill is intended to grind corn ; but in fome cafes, it is better to fix a cog-wheel on the upper part of the vertical axis with teeth round its edge, to give motion to trundles or pinions on the fpindles of the mill-ftones, becaufe the floats of the wheel muft always be made to move with a given proportion of the velocity of the water. The wheel-race or water-courfe may be made nearly the fame as for an underfhot-wheel, if we fuppofe it laid down in an horizontal pofition ; that is, a trough or channel of mafonry is conftructed in which the wheel works, and the float-boards of the wheel are exactly fitted to it : at one end of this channel is the aperture or fluice through which the ftream of water iffues, and ftrikes the floats of the wheel fo as to turn it round, and the water paffes forwards and efcapes at the other end of the channel. When the water is delivered upon the wheel in an horizontal direction, or perpendicular to its axis, the float-boards fhould be inclined about twenty-five degrees to the plane of the wheel, and the fame number of degrees to the radius, fo that the loweft and outermoft fides of the float-boards may be fartheft up the ftream and be met by the water firft.

In many cafes, the water-courfe is made inclined to the plane of the wheel in fuch a degree, that the water may ftrike the float-boards perpendicular to their furfaces.

In the fouthern provinces of France, where horizontal water-wheels are generally employed, the float-boards are made of a curvilineal form fo as to be concave towards the ftream ; they are generally fegments of fpheres, or hollow wooden bowls or ladles fixed on the rim of the wheel : the water, in this cafe, is conducted through a pipe, and projected in a jet on a direction a little inclined to the horizon. When the height of water is very confiderable, this is, perhaps, the beft form for the floats, or ladles, as they are called.

The chevalier de Borda obferves, that in theory a double effect is produced when the float-boards are concave, but that the effect is diminifhed in practice, from the difficulty of making the fluid enter, and leave the curve in a proper direction. Notwithftanding this difficulty, however, and other defects which might be pointed out, horizontal wheels with concave float-boards are always fuperior to thofe in which the float-boards have plane furfaces.

Mr. Smeaton conftructed a fmall corn-mill with a horizontal water-wheel, of which the following are the principal dimenfions. Fall of water $52\frac{1}{2}$ feet ; diameter, or bore of the nofe-pipe through which the water iffued in a jet to ftrike upon the wheel, $1\frac{1}{2}$ inch ; diameter of the water-wheel 10 feet to the centre of the floats or ladles, which were twelve in number ; they were made of a concave form, nearly fegments of fpheres, and about 14 inches in diameter ; and fixed round the circumference of the wheel, fo that the planes of the circular rims, or edges of the hollow ladles, were not perpendicular to the plane of the wheel, but inclined thereto in fuch a degree, that the jet of water iffuing from the nofe-pipe at an angle of 22 degrees from the horizontal line, would ftrike the floats in the centre and perpendicular to the circular edge of the hollow ; the internal furface of the floats being really fpherical, the water would always ftrike perpendicularly into the concavity of the bowl. The water-wheel axis rofe up perpendicularly into the mill-houfe, and on the top a wheel of 4 feet 8 inches in diameter, and 44 cogs, was fixed for giving motion to the pinions on the axis of the mill-ftones. The largeft pinion of 17 cogs was fixed on the axis of a pair of ftones 4 feet 6 inches in diameter, and the fmaller pinion of 13 cogs on the axis of a ftone 3 feet 6 inches in diameter. It was not intended to turn both thefe pairs of ftones at the fame time, but it was neceffary to have two pairs for different ufes.

When this mill moved with a proper velocity to grind to the greateft advantage, if the 4 feet 6 inches ftones were ufed, the water-wheel made 25 revolutions *per* minute, and the ftones therefore made 65 revolutions *per* minute, and the float-boards moved with a velocity of 784 feet *per* minute ; but when turning the fmaller mill-ftones of 3 feet 6 inches diameter, the water-wheel went beft when it made 26 revolutions, and therefore turned the mill-ftone 88 turns *per* minute ; and the velocity of the floats was 816 feet *per* minute.

Mr. Smeaton calculated the velocity of the water iffuing from the pipe at 3403 feet *per* minute, which is the velocity due to a 50 feet feet, becaufe he allowed the $2\frac{1}{2}$ feet to overcome friction, and the expenditure of the $1\frac{1}{2}$ inch nofe-pipe at 30 cubic feet *per* minute allowing for friction. This mill ground one bufhel of wheat *per* hour, on the average of a great many experiments, now $30 \times 50 = 1500$ cubic feet, falling one foot *per* minute. It is found by repeated experiments, that 600 cubic feet falling one foot *per* minute on a good water-wheel is an ample allowance for grinding a bufhel of wheat, as it may be done by 530; hence this fall of water ought to have ground $2\frac{1}{2}$ bufhels *per* hour inftead of one. The mill, however, admits of improvement in making the floats of the wheel move quicker.

When the mill-ftone of an horizontal mill is fixed on the upper end of the axis of the water-wheel, if the mill-ftone be five feet in diameter, it fhould never make lefs than fixty turns in a minute, and the wheel muft perform the fame number of revolutions in the fame time ; and in order that the effect may be a maximum, or the greateft poffible, the velocity of the current muft be more than double that of the wheel.

Suppofe the mill-ftone, for example, to be 5 feet diameter, and the water-wheel 7 feet, it is evident that the mill-ftone and wheel muft at leaft revolve 60 times in a minute ; and fince the circumference of the wheel is 22 feet, the float-boards will move through that fpace in the 60th part of a minute, that is, at the rate of 22 feet *per* fecond ; which being doubled, makes the velocity of the water 44 feet one fecond, anfwering, as appears from the rule, for the velocity of falling water, to a fall of 30 feet. But if the given fall of water be lefs than 30 feet, we may procure the fame velocity to the mill-ftone, by diminifh-

ing the diameter of the wheel. If the wheel, for inſtance, is only 6 feet diameter, its circumference will be 18.8 feet, and its floats will move at the rate of 18.8 feet in a ſecond, the double of which is 37.6 feet *per* ſecond, which anſwers to a head of water 22 feet high. The diameter of the water-wheel, however, ſhould never be leſs than 6 or 7 feet, becauſe the float-boards change their direction ſo rapidly, in conſequence of their proximity to the centre, that they will not receive the full action of the water, becauſe it acts in a perpendicular direction to the float-board only for a moment. Hence there will be a certain height of the fall, beneath which the ſimple horizontal wheel cannot be employed; and beyond that, wheel-work muſt be introduced to obtain the requiſite velocity for the millſtones.

In the provinces of Guienne and Languedoc, in France, another ſpecies of horizontal wheel is employed for turning machinery. It conſiſts of an inverted cone, with ſpiral float-boards of a curvilineal form winding round its ſurface. The wheel moves on a vertical axis in a pit or well of maſonry, to which it is exactly fitted, like a coffee-mill in its box. It is driven chiefly by the impulſe of the water, conveyed by a ſpout or canal in a ſtream, which ſtrikes the oblique float-boards; and when the water has ſpent its impulſive force, it deſcends along the ſpiral float-boards, and continues to act by its weight till it reaches the bottom, where it is carried off by a canal. The idea of this machine is ingenious. The jet of water, being firſt applied to the upper or largeſt part of the cone, ſtrikes the float-boards at the part where they move with the greateſt velocity, in conſequence of their being on the largeſt radius; but as the water loſes its velocity, in conſequence of the motion it has imparted to the wheel, it deſcends in the cone, and acts upon the floats lower down, where, the radius being leſs, the floats move more ſlowly, and are therefore better adapted to receive the action of the water with its diminiſhed velocity.

M. Mannoury Dectot's horizontal Water-Wheel, which he calls Danaide.—This receives the impulſe of the water in a different manner from any which we have deſcribed, and is deſcribed in a report to the Inſtitute of France in 1813. The water-wheel is fixed in a horizontal poſition upon a vertical axis, and ſupported upon the pivots thereof, ſo as to be capable of turning round. It is not in reality a wheel, but a hollow cylinder or drum capable of containing water; it is open at top, and united to the axis in the centre of the circular plane, which forms the bottom. Within this drum, and concentric with it, a ſolid cylinder is fixed; it is of leſs dimenſions than the drum itſelf, and occupies ſuch portion of the content of the drum as to reduce the open part which can contain water to a hollow ring or circular trough, open at top, and of a conſiderable depth, but only a few inches in width. The depth is deſcribed as being nearly as great as the diameter of the wheel.

The water coming from an elevated reſervoir, is projected in jets from one or more pipes into this annular ſpace which ſurrounds the rim of the wheel. Theſe pipes deſcend in an inclined direction, till they are nearly on a level with the ſurface of the water in the annular ſpace; and the extremities turn horizontally, ſo as to project the jet horizontally, and in the direction of tangents to the mean circumference of the water contained in the annular ſpace.

Suppoſe this ſpace which ſurrounds the wheel is full of water, then the ſtream iſſuing from the jet cauſes the wheel to turn round upon its axis, becauſe it takes hold or acts upon the water in the annular ſpace, and tends to give the water a circulating motion within the annular ſpace; but the friction, or reſiſtance, which the water would find in ſuch circulation, cauſes the wheel to turn round with the water, unleſs the load on the wheel, or reſiſtance to its motion, is too great.

The water which is continually thrown into the wheel eſcapes from the annular ſpace by paſſages which proceed from the bottom thereof to the centre of the wheel; and there are openings at the centre, where the water can drop out *below*. To form the paſſages for this purpoſe, the ſolid cylinder which is fixed in the centre of the hollow drum is of leſs depth than the other, and leaves a ſpace between the bottom of the ſolid and the bottom of the hollow, which is divided into compartments by diaphragms fixed upon the bottom of the trough, and proceeding like radii from the circumference to a central hole in the bottom of the trough, which is left open to allow the water to eſcape. The report ſtates, that the velocity with which the water iſſues from the jets makes the machine move round its axis; and this motion accelerates by degrees, till the velocity of the water in the annular ſpace equals that of the water from the reſervoir, ſo that no ſenſible ſhock is perceived of the affluent water upon that which is contained in the machine. The motion of the wheel is regular, becauſe the action is continual; but in the caſe of other water-wheels, where the water ſtrikes againſt float-boards, ſuch boards muſt neceſſarily be of a determinate number, and the motion muſt be given to the wheel by a ſucceſſion of impulſes, as the floats arrive before the ſtream. We might indeed ſuppoſe a wheel with an infinite number of floats, but it would then amount to a plain cylindrical or flat ſurface, upon which the water would not take ſufficient hold to produce any ſenſible effort to turn it round.

Now in M. Dectot's wheel, in place of float-boards, the rim of the wheel is clothed with water, which is capable of being acted upon by the water iſſuing from the jets. This action tends to put the water in the annular ſpace in motion, and to carry the wheel along with it, by the adheſion it muſt naturally have to the ſides of the channel which contains it. The velocity of the wheel will be in proportion to the reſiſtance that the load makes to its motion.

The circular motion of the wheel communicates a centrifugal force to the water contained in the annular cavity of its rim, which cauſes it to preſs againſt the outermoſt ſide of the channel. This centrifugal force acts equally upon the water contained in the compartments at the bottom of the ſaid rim; but its action diminiſhes as the water approaches the centre.

The whole maſs of water is then animated by two oppoſite forces, *viz.* gravity and the centrifugal force. The firſt tends to make the water run out at the hole in the bottom of the wheel at the centre, and the ſecond to drive the water from that hole.

To theſe two actions are joined a third, *viz.* friction or reſiſtance, which acts an important and ſingular part; and in this machine the friction of the water produces its powers of action, while in moſt other machines it always diminiſhes their powers. The effect in this machine would be nothing, were it not for the reſiſtance which the water finds oppoſed to its free circulation in the annular ſpace round the rim of the wheel.

By the combination of theſe three forces there ought to reſult a more or leſs rapid flow of water from the hole in the centre at the bottom of the wheel; and the ſlower this water iſſues, the greater will be the effective power of the machine for producing the uſeful effect for which it is deſtined.

The moving power in this machine, like all others, is the weight of the water which runs into the wheel, multiplied

by the elevation the reſervoir has above the bottom of the wheel, or orifice from which it iſſues in quitting the ſame; but the uſeful mechanical effect is ſtated to be equal to that product, diminiſhed by half the force which the water retains, when it flows out at the orifice below, and quits the machine.

In order to aſcertain, by direct experiment, the magnitude of this effect, Meſſrs. Prony and Carnot fixed a cord to the axis of the machine, which paſſing over a pulley, raiſed a weight by the motion of the machine. By this means the effect was found to be $\frac{7}{10}$ths of the power, and often approached $\frac{78}{100}$ths, without reckoning the friction of the pulleys, which has nothing to do with the effect.

We cannot help ſuſpecting ſome miſtake in theſe experiments, or in the ſtatement of them, but think the machine deſerves a trial; and if it ſhould produce near the reſult above ſtated, it would be a moſt valuable addition to our means of employing falls of water; and its ſimplicity would be a great recommendation, particularly for corn-mills, becauſe the perpendicular axis is immediately adapted for that purpoſe, without any wheel-work.

Horizontal Mill with oblique Vanes.—In Belidor's Architecture Hydraulique he deſcribes a different form of horizontal mill. The wheel is a circular rim, and the radii or arms are all oblique vanes or floats, preciſely the ſame as the common ſmoke-jack. This wheel is placed horizontally in a well, to which it is exactly fitted, but the rim of the wheel does not touch the circular wall of the well. The axis of the wheel aſcends upwards into the mill-houſe, and the ſpindle of the mill-ſtone is fixed into it. A horizontal arch-way is conducted to the well ſideways, and above the part where the wheel is ſituated. This arch conveys the water into the well over the wheel; and beneath the wheel there is a ſimilar horizontal arch to carry away the water, after it has paſſed through the wheel, that is, in the ſpaces between its vanes or floats. The weight of the water preſſes upon them in a perpendicular direction, and the planes of theſe floats being all inclined to the horizon, the action of the preſſure tends to turn the wheel round on its axis, by the ſame action as the ſmoke upon the vanes of a jack, or like a wind-mill.

The water is ſupplied in ſuch a body through the upper arch, that the well is always kept full, with a conſiderable depth of water preſſing upon the wheel; whilſt the lower arch carries away the water ſo freely, that it runs away from beneath the wheel as faſt as it can paſs through the vanes of the ſame.

The mill deſcribed by Belidor was at Toulouſe, and contained a number of ſuch wheels in a row, each giving motion to one pair of ſtones.

Horizontal Machines moved by the Reaction of Water.—The reaction of water, iſſuing horizontally through a ſpout or orifice, may be employed to communicate motion to machinery; and though this principle has not yet been adopted in practice, it appears from theory, and from ſome detached experiments on a ſmall ſcale, that a given quantity of water, falling through a given height, will produce greater effects by its reaction than by its impulſe. If we ſuppoſe a vertical pipe of any given height, open at both ends, and that water is poured into it at the top, the water will iſſue at the bottom of the pipe with a velocity proportioned in a certain manner to its altitude, becauſe every particle of water which iſſues is preſſed upon and impelled by the weight of all the particles which are above it. Now, ſuppoſe the pipe bent or curved at the bottom, ſo that it will turn the ſtream of water into a horizontal poſition; in this caſe, the preſſure and force, of which we have ſpoken, will be deflected from the vertical direction to the horizontal. Now it is clear that the bent part of the pipe, or ſome part of the interior ſurface of the tube oppoſite to the orifice, muſt ſuſtain all the preſſure which is thus deflected or tranſmitted in another direction; and if the tube is freely ſuſpended, it will retreat before this preſſure, and be put in motion. If we ſuppoſe the tube to have no reſiſtance to motion, then it would receive all the motion of the water, which would not move at all after it iſſued from the orifice, but the orifice and tube would move away from the water. This is an impoſſible caſe, and in reality the motion of the effluent water will be divided between the pipe or tube and the iſſuing water, in proportion to the reſiſtance with which each is loaded. Another and perhaps more familiar explanation is, that the water preſſes againſt every part of the interior part of the pipe, except againſt the orifice or aperture, which is open; and in conſequence, the unbalanced preſſure on the part oppoſite to the orifice will tend to put the pipe in motion. A ſky-rocket mounts in the air from a ſimilar cauſe.

Dr. Barker's mill by the reaction of water was the firſt of this kind of machines, and is deſcribed by Deſaguliers, in 1743. In his Experimental Philoſophy, vol. ii. p. 460, he calls it a machine to prove Mr. Parent's propoſition experimentally, *viz.* that an under-ſhot water-mill does moſt work, when the water-wheel moves with only a third part of the natural velocity of the water that drives it. He ſays, that Dr. Barker had this thought, and communicated it to him, ſaying, that it would be an experimental proof of Mr. Parent's propoſition; in conſequence of which, Deſaguliers made a working model of it, which he ſhewed to the Royal Society, and the experiments upon it, at their meeting in 1742.

It conſiſts of an upright pipe or trunk, communicating with two horizontal branches, like an inverted T; thus, ⊥. This perpendicular pipe is poiſed upon a pivot at the lower end, and the upper end is connected with the ſpindle of the mill-ſtone, or other machine to which it is to communicate motion. The top of the pipe is formed into a funnel, into which a ſtream of water is conducted, and runs down the pipe: the water eſcapes through a hole in each of the horizontal arms, which holes are near the ends of the arms, and open in oppoſite directions, and in ſuch a poſition that they will direct the ſtream of water horizontally, and nearly at right angles to the length of the arms.

Suppoſe water to be poured in at the top of the tube from the ſpout, it will then run out by the holes at the ends of the arms, with a velocity correſponding with the depth of theſe holes beneath the ſurface of the water in the vertical pipe. The conſequence of this muſt be, that the arms muſt be preſſed backwards, for there is no ſolid ſurface at the hole on which the lateral preſſure of the water can be exerted, while it acts with its full force on the inſide of the tube oppoſite to the hole. This unbalanced preſſure, acting upon the oppoſite ſides of both arms, will make the tube and the horizontal arm revolve upon the ſpindle as an axis.

This will be more eaſily underſtood, if we ſuppoſe the orifices to be ſhut up, and conſider the preſſure upon a circular inch of the arm oppoſite to the orifice, the orifice being of the ſame ſize.

The preſſure upon this circular inch will be equal to a cylinder of water, whoſe baſe is one inch in diameter, and whoſe altitude is the height of the fall; and the ſame force is exerted upon the ſhut-up orifice. Theſe two preſſures being equal, and acting in oppoſite directions, the arm will remain at reſt; but as ſoon as the orifice is opened, the water will iſſue with a velocity due to the height of the fall. The preſſure of the water upon the orifice will now be removed, and as the preſſure upon the circular inch oppoſite

to the orifice ftill continues, the equilibrium will be deftroyed, and the arm will move in a retrograde direction, unlefs it is withheld by fome force greater than that preffure.

In the original model made by Defaguliers, the vertical tube was a cylindrical pipe, but the lower arms were of a fquare figure in their crofs fection, and the apertures through which the water iffued were likewife of a rectangular figure, and provided with fliders or fluices, which were regulated by fcrews fo as to increafe or diminifh the openings.

It is clear that the machine muft prefs backwards, and there is no difficulty in underftanding the intenfity of this preffure, when the machine is at reft. But when it is allowed to run backwards, withdrawing itfelf from the preffure, the intenfity of it is diminifhed; and if no other circumftances intervened, it might not be difficult to fay what particular preffure correfponded to any rate of motion. Defaguliers affirms the preffure to be the weight of a column, which would produce a velocity of efflux equal to the difference of the velocity of the fluid and of the machine: and hence he deduces, that its performance will be the greateft poffible, when its retrograde velocity is one-third of the velocity acquired by falling from the furface; in which cafe, it will raife $\frac{4}{27}$ths of the water expended to the fame height.

But this is not a perfect account of the operation; for the water which iffues defcends in the vertical trunk, and then moving along the horizontal arms, partakes of their circular motion. This excites a centrifugal force, which muft be exerted againft the ends of the arms by the intervention of the fluid. The whole fluid contained in the arms is fubject to this action, each part in a degree proportioned to its diftance from the axis, becaufe every particle is preffed with the accumulated centrifugal forces of all the fections that are nearer to the axis. This increafes the velocity of revolution, and this mutual co-operation would feem to lead to a continual acceleration in the velocity of both motions. But, on the other hand, this circular motion muft be given anew to every particle of water, when it enters the horizontal arm. This can be done only by the motion already in the arm, and at its expence; neither can the perpendicular tube furnifh an unlimited fupply. Thus there muft be a velocity which cannot be exceeded even by an unloaded machine.

Improved Form of Dr. Barker's Mill.—This confifts in introducing the fupply of water at the lower end of the tube, inftead of the upper end. It was firft propofed by M. Mathon de la Cour, in the Journal de Phyfique, 1775, and the invention was, 20 years afterwards, claimed by a Mr. Ramfey, and very recently by M. Mannoury Dectot in France. This laft machine is very highly recommended by Meffrs. Perier, Prony, and Carnot, in a report to the Inftitute, from which we make the following extracts.

The water is introduced into the revolving arms at the lower part, through the axle: the pipe which brings the water enclofes the pivot, upon which it turns. This water is brought to the refervoir through a curved canal, by means of which the revolving arms, and the mill which it puts in motion, are placed by the fide of the refervoir, and neither above nor below it, which would much injure the working, and the fimplicity of the machine. By bringing the water from below, by means of a canal, the machine is reduced to a fimple water-wheel, the axis of which is fixed immediately to the moving mill-ftone.

Although the water enters with little velocity into the revolving arms, it caufes them to turn very faft, becaufe the apertures for its egrefs being much fmaller than thofe for its entrance, the velocity at the entrance is reciprocally much fmaller than it is at the egrefs. But this velocity at the egrefs is not an abfolute motion; it is only a relative motion with refpect to the tube from which it iffues, otherwife there would refult a fpontaneous augmentation of power, which would not agree with the principles of mechanics.

The apertures for the entrance and the egrefs of the water being proportioned as they ought to be, in order to obtain the greateft effect; then the report ftates,

1. The reaction, that is, the force of preffure which acts upon the revolving arms, at each of the apertures of egrefs, is equal to the weight of a column of water of the fame bafe as the aperture, and of the height of the level of water in the refervoir.

2. The velocity of the rotation of the arms meafured at the fame points is to the velocity due to the height of the level of the water in the refervoir, as the aperture for the entrance of the water into the mill-wheel is to the fum of the apertures of egrefs.

Whence it follows, by multiplying this force and this velocity, that the effect produced by the machine in a given time is equal to the weight of all the water that the refervoir can furnifh during this time, by the height of the level of the water in the refervoir. Now this product, it is well known, is the utmoft that can be obtained by the beft hydraulic machines.

This difpofition of Dr. Barker's machine has a confiderable advantage, which is, that the column of water which enters into the arms, by preffing from below on the part above, with all the weight of the refervoir, fuftains a great part of the weight of the machine, and confequently greatly diminifhes the friction of the pivot againft the focket in which it turns; while, on the contrary, when the water enters at the top, as in the old reacting machines, which is already very heavy of itfelf, this flowing water confiderably augments the weight, and confequently the refiftance.

This difpofition cannot be ufed, except where the bulk of water is not very confiderable.

As the arms turn, while the conduit which brings the water is immoveable, the pipe that brings the water to enter the collar of the arms is rather lefs than the collar, fo as to leave very little play between them, and is made tight by furnifhing this fmall interval with a leather collar. Another method is by furnifhing the tube at bottom, which is fixed, and the moveable collar of the wheel, with feveral cylindrical and concentrical furfaces, which fit one into the other without touching. The water fills the deep and clofe grooves formed by the cylindrical furfaces, and is fufficient to prevent that which is forced into the wheel from efcaping by the fides.

Dr. Robinfon defcribes a fuperior method of making fuch a joint, as will admit of a free motion, without any lofs or leakage. This is to make the fixed and moveable tubes very true at the joints, fo that one enters into the other, but do not touch. The two tubes are to be made exactly of the fame diameter withinfide at the joint, fo that a band of thin leather can be applied withinfide of the joint, to cover the crevice: this muft be fixed to the interior of the ftationary tube, and the revolving part being fmooth withinfide, will have very little friction, as it is only rubbed by the leather; but there can be no leakage at the joint, becaufe the water will prefs the leather clofe to the moving tube, but as much water will get in between the leather and the moving tube as to make it move fmoothly.

Theory of Barker's Mill.—This is a moft delicate fubject,

and upon which it does not appear that sufficient experiments have been made to found a certain theory.

Mr. Waring, of the American Philosophical Society, has given a theory of Barker's mill with the last-mentioned improvement, and, contrary to every other philosopher, he makes the effect of the machine equal only to that of a good undershot wheel, moved with the same quantity of water falling through the same height.

Mr. Gregory, in his Mechanics, vol. ii. has given this paper with some corrections, and recommends it as the best theory. The following rules, deduced from his calculus, may be of use to those who may wish to make experiments on the effect of this interesting machine.

1. Make each arm of the horizontal rotatory tube or arm of any convenient length, from the centre of motion to the centre of the apertures, but not less than one-third (one-ninth according to Mr. Gregory) of the perpendicular height of the water's surface above their centres.

2. Multiply the length of the arm in feet by .6136, and take the square root of the product for the proper time of a revolution in seconds, and adapt the other parts of the machinery to this velocity; or if the required time of a revolution be given, multiply the square of this time by 1.629 for the proportional length of the arm in feet.

3. Multiply together the breadth, depth, and velocity *per* second, of the race, and divide the last product by 18.47 times (14.27 according to Mr. Gregory) the square root of the height, for the area of either aperture.

4. Multiply the area of either aperture by the height of the fall of water, and the product by 41⅗ pounds (55.775 according to Mr. Gregory) for the moving force, estimated at the centres of the apertures in pounds avoirdupois.

5. The power and velocity at the aperture may be easily reduced to any part of the machinery by the simplest mechanical rules.

The only account we have of an actual machine, except the first model by Desaguliers, is by M. Mathon de la Cour, who saw one at Bourg Argental, of the following dimensions. Length of the revolving arms seven feet eight inches, and diameter three inches; diameter of each orifice 1¼ inch; fall of water, from the level surface in the reservoir to the apertures in the revolving arms, twenty-one feet. The water was introduced at the lower end of the revolving axis, through an opening of two inches, the two surfaces being fitted together by grinding.

When this machine was performing no work, and emitted water by one hole only, it made 115 turns *per* minute. This gives a velocity of (24 feet circumference × 115 =) 2760 feet *per* minute for the hole; but the effluent velocity by theory would be only 2215 feet *per* minute at 21 feet height, and in reality would be little more than six-tenths of that velocity, or about 1370 feet *per* minute. Dr. Robinson supposes even this to be much less than the velocity with which the water issued from the pipe, as we may readily believe, because all the force of the machine was expended in working like a centrifugal pump, to draw the water out of the pipe of supply, with a velocity greater than that with which it would run by the pressure of the column alone. The empty machine weighed 80 pounds, 28½ pounds of which would be borne up by the pressure of the column of 21 feet on a two-inch base, so that the friction of the pivot would be much diminished. We have no account of any work done by the machine, as it was only employed to turn a ventilator for a large hall.

Euler's Machine to act by the Reaction of Water.—His machine consists of a hollow conchoidal ring, that is, a solid shaped just like a large church bell. Suppose also another bell, of smaller dimensions, placed within the former, and leaving a space all round between the two, the two bells are joined at the lower edges, so that the water cannot escape from the space between them. This machine is mounted on a perpendicular axis, and on the top is a sort of funnel bason, which receives the water from the spout, not in the direction pointing towards the axis, but in the direction of a tangent, and the water is delivered with the precise velocity of the wheel's motion. This prevents any retardation by dragging forward the water. The water passes down from the funnel or bason between the outer conchoid or bell, and the inner conchoid, through spiral channels formed by partitions soldered to both conchoids. The curves of these channels are determined by a theory which aims at the annihilation of all unnecessary and improper motions of the water, but which is too abstruse to find a place here. The water thus conducted arrives at the bottom of the space between the two bells. On the lower circumference of this bottom is arranged a number of spouts, one from each spiral channel, which are all directed horizontally, and turned one way in tangents to the circumference.

The same effects will be produced, if we suppose only one bell, with a number of tubes or pipes wound in a spiral direction round its external circumference, the lower ends of each tube being turned horizontally, and in the direction of tangents to the circle which it describes, also the upper or higher extremities of the tubes, connected with a circular superficies into which the water flows from a reservoir. When the machine has this form, it has been shewn by Albert that the effect will increase as the velocity is augmented, and that the maximum effect would be produced if the velocity could be infinite, and that then the effect would be equal to the power. A considerable portion of the power must, however, be consumed, in communicating to the fluid the circular motion of the tubes; and, as the portion thus lost must increase with the velocity of the tubes, the effect will not in reality sustain an augmentation from an increase of velocity, beyond a certain point.

It is plain that this form of the machine must be a most cumbrous mass; even in a small size and height it would require a prodigious vessel, and must carry an unwieldy load. If we examine the theory which recommends this construction, we find that the advantages, though real and sensible, bear but a small proportion to the whole performance of the simple machine, as invented by Dr. Barker. It is therefore to be regretted, that engineers have not attempted to realize the first project.

Machines actuated by the Weight of Water.—The principal of these are breast-wheels, overshot-wheels, chains of buckets, and pressure-engines. All these have an essential difference from the machines which we have yet described, because the water is prevented from descending, unless the machine moves before the water. This is not the case with the machines which receive their motion from the impulse of the water, because the water is suffered to descend and acquire its full velocity before it strikes the machine.

In reasoning without experiment, we might be led to imagine, that, however different these modes of application are, yet whenever the same quantity of water descends through the same perpendicular space, the effective powers of two machines, which are actuated by such fall of water, would be equal, provided that the machines were free from friction, and equally well calculated to receive the full effect of the power of water, and to make the most of it.

For if we suppose the height of a column of water to be thirty inches, and that it rests upon a base or aperture of one inch square, then every cubic inch of water that departs

from the lower end of the column will acquire the fame velocity of motion, from the uniform preffure of the thirty cubic inches which are above it, that one cubic inch let fall from the top would acquire in falling down to the level of the aperture, *viz.* fuch a velocity as in a contrary direction would throw or project it to the level from whence it fell, the weights and velocities in both thefe cafes being equal, the products, or what we have called mechanical powers, will alfo be equal. We might therefore be led to fuppofe, that a cubic inch of water, let fall through a fpace of thirty inches, fo as to inpinge upon a folid body, would be capable of communicating thereto an equal motion or mechanical effect by collifion, as if the famé cubic inch had defcended through the fame fpace with a flower motion, and produced the effect gradually; for in both cafes gravity acts upon an equal quantity of matter through an equal fpace.

It is true that the gravitating force acts a longer fpace of time upon the body that defcends flowly, than upon the other which falls quickly; but this cannot occafion the difference in the effect: for we find by experiment, that an elaftic body falling through any given fpace will, by collifion upon another elaftic body which is fixed, rebound nearly to the height from which it fell: or, by communicating its motion to a body equal to itfelf, will caufe that body to afcend to the fame height. On thefe principles we might conclude, as fome authors have done, that whatever was the ratio between the power and effect in underfhot wheels, the fame would hold true in overfhot, and indeed in all others.

However conclufive this reafoning may feem, it will appear, in the courfe of the following deductions, that the effect of the gravity of defcending bodies is very different from the effect of the ftroke, of fuch as are *non-elaftic*, though generated by an equal mechanical power.

It is true that, in the cafes we have above fuppofed, the power of the fall of water is the fame; but the problem propofed to the engineer is, to obtain from it all or as much as poffible of the power, and render it applicable to fome ufeful purpofe. We have already given our definition of *power*, that it is weight or matter compounded with motion. Now to obtain all the power from any ftream of water, we muft abftract from it all its weight and all its motion. In underfhot wheels, or any others moved by the impulfe of the water, we cannot come near this, becaufe we have already fhewn, that the greateft effect is produced, when the velocity of the wheel is two-fifths of the velocity of the moving water. The water, after it has finifhed its effect, is difcharged with that velocity; hence it retains and carries away with it three-fifths of its original power. Neither can we obtain the full effect of the weight of the water, for another lofs is fuftained, in the change of figure which the water experiences, when it ftrikes the float-board. This is much greater than is ufually fuppofed, in confidering machines, although it muft be familiar to any one who confiders the refiftance of a boat, or other body, when drawn through water. No weight is raifed in thefe cafes, unlefs the motion be rapid, (fo as to raife a wave before the moving body;) but all the power is expended in changing the figure of the water, by dividing the particles, and putting them in new pofitions, fo that the body can pafs between them.

It is to this fource that we muft look, for the difference between two-fifths of the power, which we find is abftracted from the whole power of the water by an underfhot-wheel, and one-third of the power, which is the utmoft we can obtain by means of an underfhot wheel.

In the other clafs of machines, which are actuated by the weight of water, we can obtain a much greater fhare of the power of the defcending water. The weight of the water is borne by the machine, which muft therefore receive the whole weight of the water, and the lofs is chiefly in the motion which the water ftill retains after departing from or quitting the machine; but as we are not confined, as in the former inftance, to any fixed velocity of motion for the wheel, we may make it move almoft as flowly as we pleafe, fo that the water will carry away with it a very fmall fhare of the velocity which it would have acquired by falling through the height of the fall. Indeed, if we could fuppofe a wheel to be without friction, and no water to leak or efcape from thofe veffels, or parts of the wheel which contain the water, it would be poffible to obtain an effect from it very nearly equal to the power.

Breaft-Wheels.—Thefe are very commonly called underfhot wheels, becaufe the water runs beneath the wheel, but improperly, becaufe the water does not fhoot againft the floats of the wheel, or at leaft the principal power is derived from the weight of the water. A breaft-wheel partakes of the nature of both an overfhot and an underfhot, and is conftructed as is reprefented in *fig.* 1. *Plate* I. of *Water-wheels.* The lower part of the wheel is furrounded by a curved wall or fweep of mafonry, which is made concentric with the wheel, and the float-boards of the wheel are exactly adapted to the mafonry, fo as to pafs as near as poffible thereto without touching it; and the fide walls are in like manner adapted to the end of the float-board or fides of the wheel, the intention being, that as little water as poffible fhall be able to pafs by the float-boards without caufing the boards to move before it. The water is poured upon the wheel over the top of the breafting at I, the efflux from the mill-dam R being regulated by the fluice or fhuttle M, which is placed in the direction of a tangent to the wheel, and is provided with a rack N, and pinion P, by which it can be drawn up fo as to make any required degree of opening, and admit more or lefs water to flow on the wheel.

The water firft ftrikes on the float, and urges it by its impulfe; but when the floats defcend into the fweep, they form as it were clofe buckets, each of which will contain a given quantity of water, and the water cannot efcape from thefe buckets except the wheel moves, at leaft this is the intention, and the wheel is fitted as clofe as it can be to the race with that view. Each of the portions of water contained in thefe fpaces bears partly upon the wall of the fweep, and partly upon the floats of the wheel; and its preffure upon the floats, if not exceeded by the refiftance, will caufe the wheel to move; hence the action upon all the floats which are within the fweep of the breafting is by the weight of the water alone; but the water is made to impinge upon the firft float-board with fome velocity, becaufe the furface of the water in the dam K is raifed confiderably above the orifice beneath the fhuttle where the water iffues.

The upper part of the fall at I is rounded off to a fegment of a circle called the crown of the fall, and the water runs over it. The lower edge of the fhuttle when put down is made to fit to this curve, fo as to make a tight joint; and in confequence when the fhuttle is drawn up, the water will run between its lower edge and the crown in a fheet or ftream which ftrikes upon the firft float that prefents itfelf, nearly in a direction perpendicular to the plane of the float-board, or of a tangent to the wheel. The float-boards of the wheel are directed to the centre, but there are other boards placed obliquely which extend from one float-board to the rim of the wheel, and nearly fill the fpace between one float-board and the next. Thefe are called rifing-boards, and the ufe of them is to prevent the water flowing over the float-board into the interior of the wheel; but the edges of

theſe boards are not continued ſo far as to join to the back of the next float, becauſe that would make all the boards of the wheel cloſe, and prevent the free eſcape of the air when the water entered into the ſpaces between the floats.

As the water ſtrikes with ſome force, the riſing-board is very neceſſary, to prevent the water from daſhing over the float-boards into the interior of the wheel.

This is the form of breaſt-wheel employed by Mr. Smeaton in the great number of mills which he conſtructed; but although he ſpeaks of the impulſe of the water ſtriking the wheel, he always endeavoured to make the top of the breaſting or crown of the fall as high as poſſible, ſo as to attain the greateſt fall and the leaſt of the impulſive action. All rivers and ſtreams of water are ſubject to variation in height from floods or dry ſeaſons, and in ſome this is very conſiderable; it was therefore neceſſary to make the crown I of the fall at ſuch a height as that in the loweſt ſtate of the water R, it would run over the crown in a ſheet of three or four inches in thickneſs, and work the wheel. When the water roſe higher in the mill-dam, it would then have a preſſure to force it through, and in that caſe would ſtrike the wheel ſo as to impel it by the velocity.

Mr. Smeaton was well aware that the power communicated by this impulſe was very ſmall. In ſome caſes, where the water was very ſubject to variation, he uſed a falſe or moveable crown, that is, a piece of wood which fitted to the crown I, and raiſed the ſurface thereof a foot or more, ſo as to obtain the greateſt fall when the water ſtood at a mean height; but when the water ſunk too low to run over this moveable crown, it could be drawn up to admit the water beneath it. This effect has ſince been produced in a more perfect manner by making the crown of the fall a moveable ſhuttle, to riſe and fall according to the height of the water in the mill-dam, by which means the inconvenience before-mentioned is avoided.

Improved Breaſt-wheel, in which the Water runs over the Shuttle.—*Fig.* 7. is a ſection of one of this kind. A is the water which is made to flow upon the float-board B, and urges the wheel by its weight only, the water being prevented from eſcaping or flowing off the float-boards by the breaſt or ſweep D D, and the ſide-walls which incloſe the floats of the wheel. The upper part of the breaſt D D is made by a caſt-iron plate, curved to the proper ſweep to line with the ſtone-work. On the back of the caſt-iron plate the moving ſhuttle *e* is applied; it fits cloſe to the caſt-iron ſo as to prevent the water from leaking between them, and the water runs over its upper edge. F is an iron groove or channel let into the maſonry of the ſide-walls, and in theſe, the ends of the ſliding ſhuttle are received; *f* is an iron rack, which is applied at the back of the ſhuttle, and aſcends above the water-line where the pinion *g* is applied to it to raiſe or lower the ſhuttle. The axis of the pinion is ſupported in a frame of wood I I; *h* H is a toothed ſector and balance-weight, which bears the ſhuttle upwards, or it might otherwiſe fall down by its own weight, and put the mill in motion when not intended. G is a ſtrong planking, which is fixed acroſs between the two ſide-walls, and retains the water when it riſes very high, as in time of floods; but in common times the water riſes only a few inches above the lower edge of the planking. When the ſhuttle is drawn up to touch this lower edge, the water cannot eſcape; but when the ſhuttle is lowered down, it opens a ſpace *e* through which the water flows upon the float-boards of the wheel. This was the form firſt adapted for the falling-ſhuttle, but its conſtruction has ſince been much improved.

Fig. 4. *Plate* II. is a ſection of the moſt improved form for a breaſt-wheel, taken from the Royal Armoury Mills, at Enfield Lock, erected by Meſſrs. Lloyd and Oſtel. The general deſcription of this, is like the former, but it is conſtructed in a better manner, and unites ſtrength with durability. The breaſt of maſonry is ſurmounted by a caſt-iron plate A 2½ feet high, which is let into the maſonry of the ſide walls at each end, and the lower part is formed with a flanch, by which it is bolted to the ſtone-breaſt at top. This plate is made ſtraight at the back for the ſhuttle B to lie againſt, and it ſlides up and down. The ends of the gate are guided by iron groove pieces or channels which are let into the ſtone-work of the ſide walls, and being made wedge-like, they fix the ends of the caſt-iron breaſt faſt in its place. The grooves are not upright, but inclined to the perpendicular ſo much, that the plane of the gate is at right angles to a radius of the wheel drawn through the point where the water falls upon the wheel. D is a ſtrong plank of wood, extended between the iron grooves juſt over the ſhuttle. When the ſhuttle is drawn up it comes in contact with the lower ſide of this piece of wood, and ſtops the water; but the piece D is fixed at ſuch a height, that the water will run clear beneath it, unleſs its ſurface riſes above its mean height.

The float-boards of the wheel do not point to the centre of the wheel, but are ſo much inclined thereto that they are exactly horizontal at the point where the water firſt flows upon them. In this way, the gravity of the water has its full effect upon the wheel, and the boards riſe up out of the tail-water in a much better poſition, than if they pointed to the centre of the wheel; and this is more particularly obſervable when the wheel is flooded by tail-water penned up in the lower part of the race, ſo that it cannot run freely away from the wheel. The dimenſions of this wheel are as follow:—Diameter 18 feet to the points of the floats, and 14 feet wide; the float-boards are 40 in number, each 16 inches wide, and each riſing-board 11 inches wide. The wheel is formed of four caſt-iron circles or wheels, each 14 feet 8 inches diameter, placed at equal diſtances upon the central axis, which is 14 feet 8 inches long between the necks or bearings, and 9 inches ſquare; the bearing-necks are 9½ inches diameter. The wheel is calculated to make four revolutions *per* minute, which gives near 3½ feet *per* ſecond for the velocity with which the float-boards move. The fall of water is ſix feet, and the power of the wheel, when the ſhuttle is drawn down one foot perpendicular, equal to 28-horſe power.

Breaſt-Wheel with two Shuttles.—In this wheel the piece of wood marked D in the laſt figure, is fitted into the groove of the ſhuttle, and is provided with racks and pinions to ſlide up and down, independently of the lower ſhuttle. The intention of this is, to make the lower ſhuttle riſe and fall, according to the height of the water, ſo that the water ſhall always run over the top of it, in the proper quantity to work the mill with its required velocity, whilſt the upper ſhuttle is only uſed to ſtop the mill by ſhutting it down upon the lower ſhuttle, and preventing the water from running over it. This plan is uſed when the mill is to be regulated by a governor, or machine to govern its velocity; in that caſe the governor is made to operate upon the lower ſhuttle, and will raiſe it up, or lower it down, according as the mill takes too much or too little water, and this regulates the ſupply; but the upper ſhuttle is uſed to ſtop the mill, and by this means the adjuſtment of the lower ſhuttle is not deſtroyed, but when ſet to work again, it will move with its required velocity. *Fig.* 3. *Plate* II., *Water-wheels*, is a ſection of one of the water-wheels at the cotton-mills of Meſſrs. Strutt, at Belper, in Derbyſhire. The width of this wheel is very great, and to render the ſhuttles A B firm, a ſtrong

grating of cast-iron, is fixed on the top of the breast K, and the shuttles are applied at the back of the grating E, so as to slide up and down against it, the strain occasioned by the pressure of the water being borne by the grating. The lower shuttle is moved by means of long screws, *a*, which have bevilled wheels, *b*, at the upper ends, to turn them, by a connection of wheel-work with the wheel-work of the mill. The upper shuttle, A, is drawn up or down by racks and pinions, *c*, which are turned by a winch, or handle. The bars of the grating E are placed one above the other, like shelves, but are not horizontal; they are inclined, so that the upper surfaces of all the bars form tangents to an imaginary circle of one-third the diameter of the wheel described round the centre thereof. These bars are not above half an inch thick, and the spaces between them are $2\frac{1}{2}$ inches. The bars are of a considerable breadth, the object of them being to lead the water, with a proper slope, from the top of the lower shuttle A to flow upon the floats of the wheel. This disposition allows the shuttles to be placed at such a distance from the wheel as to admit very strong upright bars of cast iron to be placed between the wheel and the shuttles, for the shuttles to bear against, and prevent them from bending towards the wheel, as the great weight of water would otherwise occasion them to do. These upright bars are very firmly fixed to the stone-work of the breast at their lower ends, and the upper ends are fastened to a large timber, D, which is supported at its ends in the side walls, and has a truss-framing applied to the back of it, like the framing of a roof, to prevent it from bending towards the wheel. The upright bars are placed at distances of five feet asunder, so as to support the shuttles in two places in the middle of their length, as well as at both ends; and large rollers are applied in the shuttle, where it bears against these bars, to diminish the friction, which would otherwise be very great.

These precautions will not appear unnecessary when the size of the work is known. The wheel is $21\frac{1}{2}$ feet in diameter, and 15 feet broad; the fall of water is 14 feet, when it is at a mean height; the upper shuttle is $2\frac{1}{2}$ feet high, and 15 feet long; the lower shuttle is 5 feet high, and the same length, so that it contains 75 square feet of surface exposed to the pressure of the water: now taking the centre of pressure at two-thirds of the depth, or $3\frac{1}{3}$ feet, we find the pressure equal to that depth of water acting on the whole surface; that is, the weight of $3\frac{1}{3}$ cubic feet of water = 208 lbs. bears on every square foot of surface, which is equal to 15,600 lbs., or near 7 tons on the lower shuttle only; but if we take the two shuttles together, the surface is 112 square feet, and the mean pressure 312 lbs. upon each, or 16 tons in the whole. The wheel has forty float-boards pointing to the centre. The wheel is made of cast-iron. There are two wheels of the dimensions above stated, which are placed in a line with each other, and are only separated by a wall which supports the bearings; for they work together as one wheel, and the separation is only to obviate the difficulty of making one wheel of such great breadth as 30 feet, though this is not impossible, for there is a wheel in the same works 40 feet in breadth, but it is of wood and not in iron, framed in a particular manner, as we shall soon describe.

Mr. Buchanan's Bucket Water-Wheel for a low Fall.—We have already shewn, that where water can be made to act on a wheel by weight, it is much more effectual than when the same water is made to act by impulse; and we shall shew this more fully in speaking of overshot-wheels.

Where the fall is less than half the diameter of the wheel, if the buckets are made in the usual form of the buckets for overshot-wheels, the difficulty of filling them with water, and the short time they are able to retain the water, are such great defects, that in such cases breast-wheels, with open float-boards, such as we have described, have been found in practice to be more advantageous than bucket-wheels.

Mr. Buchanan suggests, that, by adopting another form of the buckets, they might be so made as to be easily filled, and at the same time capable of retaining the water in a situation to produce nearly its full effect altogether by weight, on a low fall.

In a wheel of this construction, contrary to the usual practice, the water must be poured into the buckets from within the circle of buckets instead of from without the circle of buckets. How the filling of the buckets from within can be accomplished may not at first be obvious; but it may be done without the pentrough, which supplies the water, making any interference with the arms of the wheel, if it is constructed as shewn in *figs.* 4. and 5. *Plate* I. *Water-wheels.* *Fig.* 4. is an horizontal section of the wheel, and plan of the pentrough; and *fig.* 5. an elevation of the water-wheel.

The buckets in the figure, empty themselves by means of apertures on the outside of the wheel, which are the whole length of the buckets, but no wider than just sufficient to discharge the water from the buckets when they arrive at the bottom of the wheel, and before they begin to ascend. A A is the pentrough, into which the supply of water is conducted. From B to C a part of the wheel is represented, with the shrouding removed, to shew the form of the buckets, and the situation of the water in them; *a*, *a*, *a*, are the apertures by which the water escapes from the buckets; *b* the aperture by which the water enters from the pentrough to the buckets. The plan, *fig.* 4., shews, that the arms, N N, of the wheel, and the circular rims which support the buckets, occupy only a small part of the breadth of the circular ring of buckets M; so that about one-third of the length of the buckets at each end is exposed on the inside of the circle, and against these parts the penstock is applied, as shewn at A A, and the arms and rim of the wheel, move clear of it; but the buckets, as they pass, receive water, which flows in a continual stream at the orifices, *b*, *b*, of the pentrough; the buckets there become filled from the inside. The partition-boards or plates which form the buckets are represented by the white lines in *fig.* 5., and are so shaped, that they will retain nearly the whole of the water until they arrive at the lowest *a*; the water then begins to escape, and by the time that each bucket arrives at the lowest point of the wheel, it will have discharged all the water, and will rise up empty.

This is a truly ingenious contrivance; but we fear that in the execution it would present many difficulties, particularly the ring of buckets M, which could not, we think, be so firmly affixed, supported by the narrow bearing of the two rings and arms N, as to preserve their circular figure for any great length of time; and any bending or warping of such a heavy mass as a water-wheel will soon destroy it. Neither is the advantage which could be derived from receiving the water in close buckets, instead of open float-boards, so great as is generally imagined.

On the Power and Effect of Breast-wheels.—We shall fully examine the different effects of the power of water, when acting by its impulse and by its weight, under the title of *overshot-wheels.* In breast-wheels of the common construction, the effects of impulse and weight are combined; but what is there described being carefully attended to, the application of the same principles in these combined cases will be easy.

All kinds of machines, where the water cannot deſcend through a given ſpace, unleſs the wheel moves therewith, are to be conſidered as of the ſame nature with overſhot-wheels, and equal in power and effect to an overſhot-wheel, in which the perpendicular height that the water deſcends from is the ſame. All thoſe machines that receive the impulſe or ſhock of the water, whether in an horizontal, perpendicular, or oblique direction, are to be conſidered of the ſame nature as underſhot-wheels. Therefore, in a wheel which the water ſtrikes at a certain point below the ſurface of the water in the mill-dam, and after that deſcends in the arc of a circle, preſſing by its gravity upon the floats of the wheel, the power will be equal to the effect of an underſhot-wheel, whoſe fall is equal to the difference of level, between the ſurface of the reſervoir and the point where it ſtrikes the wheel, added to that of an overſhot, whoſe height is equal to the difference of level between the point where it ſtrikes the wheel and the level of the tail-water.

It is here ſuppoſed that the wheel receives the ſhock of the water at right angles to its radii, and that the velocity of its circumference is properly adapted to receive the utmoſt advantage of both theſe powers; otherwiſe a reduction muſt be made on that account.

Mr. Oſtel, an experienced engineer, informs us, that the velocity of the water-wheel's circumference ſhould always be between three and four feet *per* ſecond; but he has not been able to determine which of theſe two velocities is the beſt, except in caſes where a wheel is ſubject to be flooded by tail-water; and in that caſe four feet *per* ſecond is beſt. Mr. Smeaton adviſed 3½ feet.

On overſhot Water-Wheels.—An overſhot-wheel is ſimply a circular ring of open buckets, ſo diſpoſed round the circumference of a vertical wheel, as to receive the water from a ſpout placed over the wheel in ſuch a manner, that the buckets on one ſide of the wheel ſhall be always loaded with water, whilſt the other ſide is empty: in conſequence, the loaded ſide will cauſe it to deſcend; and by this motion the water runs out of the lower buckets, while the empty buckets of the riſing ſide of the wheel, in their turn come under the ſpout, and are filled with water.

A machine ſo ſimple does not appear to preſent any difficulties in its execution, which ſhould require any application of theoretic reaſoning to remove them; but in reality it is a matter of ſome delicacy to conſtruct a wheel in ſuch a manner as to obtain the greateſt effect from a given fall of water.

It is probable, that the earlieſt overſhot water-wheels conſiſted of a number of wooden boxes or bowls, faſtened on the circumference of the wheel; but theſe would ſoon give place to a better mode of conſtruction, in which the circumference of the wheel being ſurrounded by a circular ring at each ſide, the ſpace between them was divided into ſeparate buckets by partition-boards. Theſe partitions did not point to the centre of the wheel in the direction of radii, but were inclined thereto nearly in an angle of forty-five degrees. By this means, the water which iſſued from the ſpout of the trough above, nearly in an horizontal direction, as a tangent to the wheel, would run into the buckets, and fill them as they arrived in ſucceſſion at the top or higheſt point of the wheel; but as the buckets changed their poſition by the deſcending-motion of one ſide of the wheel, they would become inclined, and the water contained in the buckets would begin to run over the edges of the partitions between the buckets, and by the time the bucket arrived at the bottom point of the wheel, the whole of the water would be run out and leave the bucket empty, and they would remain empty whilſt they aſcended on the oppoſite ſide of the wheel. By this means, a conſtant preponderance of one ſide of the wheel would be kept up by the water falling into the buckets at the top of the wheel, and flowing from it at the bottom.

The points chiefly to be conſidered in conſtructing an overſhot-wheel are, firſt, that the water ſhall be applied on the circumference of the wheel, ſo as to be incapable of deſcending without communicating motion to the wheel, until the water has deſcended to its loweſt poſition, and that it ſhall then quit the wheel entirely; ſecondly, that the utmoſt height of fall ſhall be attained and uſefully employed; and thirdly, that the load or reſiſtance to the motion of the wheel ſhall be ſo adapted and proportioned to the weight of water which is applied in the deſcending-buckets of the wheels, that the wheel will move ſlowly; becauſe we have before ſhewn, that whatever velocity the wheel moves with, ſo much velocity the water muſt retain when it quits the wheel, and will thus carry away ſome power with it.

We ſhall now proceed to conſider all the particulars which contribute to the attainment of theſe objects, taking Mr. Smeaton for our guide, and only adding ſuch obſervations as appear neceſſary to render his maxims more clear.

I. *On the maximum Effect which can be obtained from a Fall of Water by Means of an overſhot-Wheel.*—The effective power of the fall of water muſt be reckoned upon the whole deſcent, becauſe it muſt be raiſed that height, in order to be in a condition to produce the ſame effect a ſecond time. The ratio between the powers of the falling water ſo eſtimated, and the mechanical effects produced by the wheel at the maximum, deduced from the mean of ſeveral of Mr. Smeaton's experiments, is as 3 to 2 nearly. We have before, in our obſervations upon the effects of underſhot-wheels, ſhewn that the general ratio of the power to the effect, when greateſt, was 3 : 1. The effect, therefore, produced by an overſhot-wheel, under the ſame circumſtances of quantity and fall of water, is at a medium, double that produced by an underſhot. From this, it appears that non-elaſtic bodies, when acting by their impulſe or colliſion, communicate only a part of their original power; the other part being ſpent in changing their figure in conſequence of the ſtroke.

The ratio of the power to the effect, computed upon the height of the wheel only, was, at a maximum, as 10 : 8, or as [illegible], becauſe Mr. Smeaton made the wheel of a leſs height than the fall of water, in order to allow ſome run or deſcent of the water through the ſpout or trough, which conducted it into the buckets of the wheel. We find the ratio, between the power and effect, to continue the ſame, in caſes where the conſtructions are ſimilar; hence we muſt infer, that the effects, as well as the powers, are as the quantities of water and perpendicular heights multiplied together reſpectively.

II. *On the moſt proper Height of the Wheel, in Proportion to the whole Deſcent.*—The preceding obſervation ſhews, that the effect which can be obtained from the ſame quantity of water, deſcending through the ſame perpendicular ſpace, is double when it is made to act by its gravity upon an overſhot-wheel, to what could be obtained from it when made to act by its impulſe upon an underſhot-wheel.

Hence it follows, that the higher the wheel is, in proportion to the whole deſcent, the greater will be the effect; becauſe an overſhot-wheel depends leſs upon the impulſe of the water when it firſt ſtrikes the wheel, and more upon the gravity of the water in the buckets. The water which is conveyed into the buckets can produce very little effect by its impulſe, even if its velocity be great; both on account of

the obliquity with which it ſtrikes the buckets, and in conſequence of the loſs of water occaſioned by a conſiderable quantity of fluid being daſhed over their ſides. Inſtead, therefore, of expecting an increaſe of effect from the impulſe of the water occaſioned by its fall through ſome part of the whole height, we ſhould cauſe it to act through as much as poſſible of this height by its gravity, by making the diameter of the wheel as great as poſſible. But a diſadvantage attends even this rule; for if the water is conveyed into the buckets with a very ſmall velocity, which muſt be the caſe when the diameter of the wheel equals the height of the fall, the velocity of the wheel will be retarded by the impulſe of the buckets ſtriking againſt the water, in order to put it in motion, and much power would be loſt by the water daſhing over them. In order, therefore, to avoid all inconveniences, the diſtance of the ſpout from the receiving-bucket ſhould, in general, be about two or three inches, that the water may be delivered with a velocity a little greater than that of the wheel; or, in other words, the diameter of an overſhot-wheel ſhould be two or three inches leſs than the greateſt height of the fall; and yet it is no uncommon thing to ſee the diameters of theſe wheels ſcarcely one-half of that height. In ſuch a conſtruction, the loſs of power is prodigious.

It is always deſirable that the water ſhould have ſomewhat greater velocity, than the circumference of the wheel in coming thereon, otherwiſe the wheel will not only be retarded by the buckets ſtriking the water, but thereby daſhing a part of it over ſo much of the power is loſt.

The velocity that the circumference of the wheel ought to have, will be known by what we ſhall ſay next, and the depth of column requiſite to give the water its proper velocity, is eaſily computed from the rules and tables given in this article, and will be found much leſs than what is generally ſuppoſed.

This maxim obliges us to uſe a wheel, whoſe diameter is nearly equal to the whole fall; but we ſhall not gain any thing by employing a larger wheel. It is true, we could then apply the water upon a part of the circumference where the weight will act more perpendicularly to the radius, but we ſhould loſe more, by the neceſſity of diſcharging the water at a greater height from the bottom, becauſe the water, in all caſes, begins to run out of the buckets long before they arrive at the bottom of the wheel.

Suppoſe the buckets of both wheels equally well conſtructed in either caſe, whether the wheel is only as high as the fall, or of a greater height, then the heights above the bottom, where they will diſcharge the water, will increaſe in the proportion of the diameter of the wheel. That we ſhall loſe more by this, than we gain by a more direct application of the weight, is plain without any further reaſoning, by taking the extreme caſe, and ſuppoſing our wheel enlarged to ſuch a ſize, that the uſeleſs part below would be equal to our whole fall. In this caſe, the water would be ſpilled from the buckets as ſoon as it is delivered into them. All intermediate caſes, therefore, partake of the imperfection of this. It was the object of Mr. Buchanan's bucket-wheel, which we have already deſcribed, to avoid this difficulty, and employ a height of fall which bore only a ſmall proportion to the whole height of the wheel. This obſervation neceſſarily leads us to conſider the beſt form for the buckets.

III. *On the beſt Form for the Buckets of overſhot Wheels.*— It is impoſſible to conſtruct the buckets ſo that they will remain completely filled with water till they reach the bottom of the wheel: indeed, if the buckets were formed by partitions directed to the axis of the wheel, the whole water muſt run out by the time they have deſcended to the level of the axis; and, in conſequence, there muſt be a great diminution in the mechanical effect of the wheel. Mill-wrights have, therefore, turned their chief attention to the determination of a form for the buckets which ſhall enable them to retain the water through a great portion of the circumference of the wheel. An inſpection of *figs.* 2 and 3 will ſhew at once the proper form which has been eſtabliſhed by long practice. Theſe are called elbow-buckets, becauſe each partition is formed by two boards, which are put together with an angle or elbow. The rule for ſetting theſe out is, to divide the wheel into the number of buckets it is intended to have; then take four-fifths of the ſpace or interval between two partitions for the depth of the ſhrouding, that is, the breadth of the circular rings at the ſides of the wheel, which form the ends of the buckets, and are called the ſhrouds; whilſt the planking, which forms the bottom of all the buckets, is called the ſole of the wheel. That board of each partition which is in the direction of a radius to the wheel, riſes from the ſole half the depth of the ſhroud; the other board of the bucket is ſo inclined, that its outer end ſhall be advanced beyond the line of the next radius-board, if it was produced.

It is a great advantage to make the partitions of the buckets thin, particularly the edges of the partitions, which will meet and divide the ſtream of water flowing upon the wheel; and if theſe edges are not made ſharp, they will ſplaſh the water about; the edges are, therefore, finiſhed by iron-plate, or it is better to make all the inclined parts of the partition of iron-plate. The greater number of buckets, and the ſhallower they are, the more regularly the wheel will act. The limits are, that the mouths of the buckets ſhall be of ſuch width as to allow the air to eſcape, at the ſame time that the ſtream of water flows in; and alſo that the breadth of the wheel ſhall not be extravagantly great, to make its buckets contain as much water as would produce the power required from the wheel.

The loſs of water, at the lower part of the wheel, will very much depend upon the proportion of water which is poured into each bucket. It is evident, that if the buckets, of whatever form they are made, were totally filled when at the top of the wheel, they muſt begin to ſpill the water immediately when they departed from that poſition. But, on the other hand, if only a part of the content of each bucket is filled with water, then it will bear a greater degree of inclination, and be a longer time before the water will begin to ſpill from the bucket. This is a reaſon for making large buckets, and filling only a part of their contents. In practice a medium muſt be ſtruck between theſe contending circumſtances, and the wheel will act to advantage.

It has been propoſed to apply another bend to the partition-boards of each bucket which ſhall be beyond the inclined board that we have deſcribed, and ſhall be concentric with the rim of the wheel, in the ſame manner as is repreſented in Mr. Buchanan's wheel, *fig.* 5. It is true that this form would retain the water from ſpilling for a longer time, and thus be an advantage; but it is not favourable for admitting the water into the buckets when at the top of the wheel.

The inclined boards, when made as we have deſcribed, may be exactly in the line of the ſtream of water, which iſſues from the ſpout when it paſſes beneath ſuch ſtream; and in this way, if the edge of the inclined board is made thin, there will be as little ſplaſhing of the water as poſſible. But by the addition of another part to the edge of the partition, which is concentric to the circle of the wheel, the ſtream of water cannot be made to proceed exactly in the

line of the partition, and will therefore ſplaſh the water. The ſplaſhing may appear immaterial, but it is in reality very prejudicial, becauſe the broken water fills the mouth of the bucket, and prevents the air from getting out readily, and it is for this reaſon that it is very neceſſary to allow ſo much of the fall above the height of the wheel, as will make the water run into the buckets, with a little greater velocity than the motion of the wheel.

Dr. Robinſon, in the Encyclopædia Britannica, deſcribed a plan for the buckets of an overſhot wheel, which was invented by Mr. Robert Burns, millwright, and executed by him at a cotton-mill in Scotland: it is ſhewn in *fig.* 5. *Plate* II. *Water-wheels.* In this way, the wheel has two ranks of buckets, one within the other. The buckets conſiſt of a partition A B, in the direction of a radius of the wheel, which is joined to another B C, inclined to that, and alſo to a third C D, which is concentric with the rim of the wheel.

The bucket is divided into two, by a partition L M, alſo concentric with the rim of the wheel, and ſo placed as to make the inner and outer portions of the bucket nearly of equal capacity. It is evident, without any farther reaſoning, that this partition will enable the double bucket to retain its water much longer than the ſingle one could. When they are filled only one-third, they retain the whole water at eighteen degrees from the bottom of the wheel, and they retain half of the water at eleven degrees. The only objection is, that they do not admit the water quite ſo freely as buckets of the common conſtruction.

This ariſes from the air, which muſt find its way out to admit the water, but is obſtructed by the entering water, and occaſions a great ſpluttering at the entry. This may be entirely prevented, by making the ſpout conſiderably narrower than the wheel, and will leave room at the two ends of the buckets for the eſcape of the air. It was found in practice, that a ſlow moving wheel, allowed one half of the water to get into the inner buckets, eſpecially when the partitions which form the inner buckets, did not altogether reach the radius drawn through the lip D of the outer bucket. The doctor conſiders this as a very great improvement of the bucket-wheel; and when the wheel is made of a liberal breadth, ſo that the water may be very ſhallow in the buckets, it ſeems to carry the performance as far as it can go. Mr. Burns made the firſt trial on a wheel of twenty-four feet diameter, and its performance is manifeſtly ſuperior to that of the wheel which it replaced, and which was a very good one. It has alſo another valuable property. When the ſupply of water is very ſcanty, a proper adjuſtment of the ſtream of water iſſuing from the ſpout, will direct almoſt the whole of the water into the outer buckets; which, by placing it at a greater diſtance from the axis, makes ſome addition to its mechanical energy.

IV. *Concerning the proper Velocity of the Circumference of an overſhot Wheel, in order to produce the greateſt Effect.*—If a body of water is let fall freely from the ſurface of the water in the upper reſervoir to the bottom of the deſcent, it will take a certain time in falling; and in this caſe, the whole action of gravity will be ſpent in giving the water a certain velocity. But if this water in falling is intended to act upon ſome machine, ſo as to produce a mechanical effect, the falling water muſt be retarded, becauſe a part of the action of gravity is then ſpent in producing the effect, and the remainder only will give motion to the falling water, which motion it will retain, after it has quitted the machine. On this principle, the ſlower a body deſcends the greater portion of the action of its gravity can be applied to produce mechanical effect, and in conſequence the greater that effect will be.

If a quantity of water falls from a ſtream, into each bucket of an overſhot-wheel, it is there retained until the wheel, by moving round, diſcharges it. Now, the ſlower the wheel moves, the more water each bucket will receive, becauſe it remains a longer time beneath the ſpout, ſo that what is loſt in the ſpeed with which the wheel moves, is gained by the preſſure of a greater quantity of water acting in the buckets at once; and if conſidered only in this light, the mechanical power of an overſhot-wheel to produce effects will be equal, whether it moves quick or ſlow. The popular reaſoning adduced to prove this has been of the following kind. Suppoſe that a wheel has thirty buckets, and that four cubic feet of water are delivered in a ſecond on the top of the wheel, and diſcharged, without any loſs by the way, at a certain height from the bottom of the wheel.

It is clear that this ſtream will ſupply the ſame quantity, whatever is the rate of the wheel's motion; and the buckets muſt be of a ſufficient capacity to hold all the water which falls into them when the wheel moves very ſlow. Suppoſe this wheel employed to raiſe a weight of any kind, for inſtance to draw a baſket of coals out of a deep pit or mine, and that the rope winds upon a barrel of ſuch ſize that the baſket will be drawn up with the ſame velocity as the water in the buckets deſcends. Suppoſe, further, that the wheel will make four revolutions in a minute, or one turn in fifteen ſeconds, when the load or weight in the baſket which forms the reſiſtance to the motion of the machine is one-third of the load of water contained in the buckets of the wheel.

Now, during the time of one revolution, ſixty cubic feet of water will have flowed into the thirty buckets, and each have received two cubic feet. In this caſe, the baſket may contain a weight equal to twenty cubic feet of water, which weight will be drawn up a height equal to one circumference of the wheel, during one turn of the wheel, or in fifteen ſeconds of time.

Now ſuppoſe the machine ſo loaded, by making the baſket more capacious, that the wheel can only make two turns in a minute, or one turn in thirty ſeconds, then each deſcending bucket of the wheel will receive four cubic feet of water. If the baſket contained a double weight, *viz.* equal to forty cubic feet, the effect produced by the machine would be the ſame as before, becauſe the velocity is only one half; but we find in practice, that it will raiſe more than in this proportion when it moves ſlower, for if we attend to what we have juſt obſerved of the falling body, we find that ſo much of the action of gravity as is employed in giving motion and velocity to the wheel and water therein, muſt be ſubtracted from its preſſure upon the buckets. The product made by multiplying the number of cubic inches of water which act on the wheel at once by its velocity, will be the ſame in all caſes; yet, as each cubic inch, when the velocity is greater, preſſes more lightly upon the buckets than when the velocity is leſs, the power of the water to produce effects will be greater in the leſs velocity than in the greater. This leads us to the general rule, that the leſs the velocity of the wheel, the greater will be the effect produced by any given quantity, and fall of water.

A confirmation of this doctrine, together with the limits it is ſubject to in practice, is a matter of experiment and obſervation which has been ably decided by Mr. Smeaton. The velocity of the wheel ſhould not be diminiſhed, further than what will produce ſome ſolid advantage in point of power; becauſe, as the motion is ſlower, the buckets muſt be made larger, that the increaſe of their weight may com-

penfate for the flownefs of their motion. The wheel being thus more loaded with water, the ftrefs upon every part of the work will be increafed in proportion.

The beft rule for practice will be, to make the velocity of the circumference a little more than three feet in a fecond.

Experience confirms, that this velocity of three feet in a fecond, is applicable to the greateft overfhot wheels as well as the fmalleft; and all other parts of the work being properly adapted to this velocity, the fall of a given quantity of water, will produce very nearly the greateft effect poffible. But it is alfo certain from experience, that large wheels may deviate further from this rule before they will lofe their power, by a given aliquot part of the whole, than fmall ones can be admitted to do; for inftance, a wheel of twenty-four feet high may move at the rate of fix feet *per* fecond, without lofing any confiderable part of its power. This may perhaps be accounted for, when we confider how fmall a proportion of the whole fall is requifite to give the water the proper velocity which the wheel ought to have; whilft in a fmaller wheel, the fame height muft be allowed for that purpofe, and confequently, a greater proportion of the whole height. On the other hand, Mr. Smeaton tells us, that he had feen a wheel of thirty-three feet diameter that moved very fteadily and well, with a velocity but little exceeding two feet *per* fecond.

There is a natural wifh to fee a machine move brifkly; it has the appearance of activity: but a very flow motion always looks as if the machine was overloaded. For this reafon, mill-wrights have always yielded flowly, and with reluctance, to the advice of Mr. Smeaton, but they have yielded; and we now fee them adopting maxims of conftruction more agreeable to found theory, that is, making their wheels of great breadth, and loading them with a great deal of work. The reluctance to adopt this fyftem did not arife folely from prejudice, but from a real inconvenience attending the flow motion of the wheel when the refiftance which is oppofed to its motion, and which is the caufe that it moves flowly, is not uniform in the different parts of a revolution.

In all machines, there are fmall inequalities of action which are unavoidable; and in fome machines very great inequalities arife, from the intermitting motions of cranks, ftampers, and other parts which move unequally or reciprocally. When a water-wheel is employed to give motion to fuch machines, it may be fo refifted or loaded, as to be nearly in equilibrio with its work, in the moft favourable pofition of the parts of the machine; but when thefe change into a lefs favourable pofition, the machine may ftop the wheel altogether, or at all events hobble, and work very irregularly. And for the fame reafon that a water-wheel accommodates its motion very quickly to the refiftance it is to overcome, fo all tendency to irregular motion is increafed. A wheel, when its load is increafed, moves more flowly, and receives more water into each bucket; thereby taking to itfelf a weight of water equal to overcome its load, and on the other hand by moving quicker, it takes lefs water into each bucket when the load is diminifhed. But thefe changes do not take place inftantaneoufly, becaufe it can be only in the moment that each bucket paffes beneath the ftream, that the fhare of water it fhall have, will be influenced by the rate of the wheel's motion. When a bucket is once filled it continues with that charge until it arrives at the bottom of the wheel.

This felf-regulating property of the wheel can only apply in cafes of fmall and permanent changes of refiftance, for it always comes too late to correct fudden and confiderable changes in the refiftance; then it acts in the contrary direction. Suppofe, for inftance, an overfhot wheel is employed to work a fingle pump by means of a crank, the refiftance of this machine will be continually varying; it will be nothing during one-half of the period of the revolution when the pump is not drawing any water, and during the other half it will be in a conftant ftate of increafe and diminution. Now, during the time this wheel has nothing to do, it will turn round very quickly, and therefore each bucket will receive very little water; confequently, when the wheel comes to be refifted, the wheel will have fo little water in its buckets, that it will perhaps be quite ftopped: in this cafe, the bucket beneath the fpout will receive water until it is quite full, and then the water will run over and fill fo many of the buckets beneath it, as to put the wheel in motion flowly; in confequence, the fucceeding buckets will receive a large fhare of water during the half revolution when the pump makes its ftroke; but when this is finifhed, and the refiftance ceafes, the wheel being well loaded with water, will in confequence move very rapidly for a half revolution, and its buckets will receive very little water.

This is indeed an extreme cafe of irregular refiftance, and muft be remedied by applying two pumps inftead of one, or a balance-weight, or a fly-wheel; but the fame principle will apply in cafe of fmaller irregularities. In all cafes, the refiftance muft be reduced to a great degree of uniformity, before a water-wheel can be applied to it with advantage, particularly if the wheel is intended to move flowly, with a view of obtaining the greateft power, the irregularities will then have more ferious confequences.

A little more velocity enables the machine to overcome thofe increafed refiftances by its *inertia*, or the great quantity of motion inherent in it. Great machines poffefs this advantage in a fuperior degree, and will confequently work fteadily with a fmaller velocity. In all cafes, the machine muft have fo much moving matter in it as is fufficient to overcome the irregularities, and regulate the motion of the wheel. If this is not already found in the machine, as in the mill-ftones of a corn-mill for inftance, the weight muft be placed in the water-wheel itfelf, or in a fly-wheel applied for the purpofe.

Mr. Buchanan meafured the quantity of water which a cotton-mill required, when going at its common velocity; and when going at half that velocity. The refult was, that the laft required juft half the quantity of water which the firft did. In the experiments, the quantities of water were calculated from the depth of water and apertures of the fluices.

From which experiments, he inferred that the quantity of water neceffary to be employed in giving different degrees of velocity to a cotton-mill, muft be nearly as the velocity. The water from the cotton-mill on which he made the obfervation, falls a little below it, into a perpendicular-fided pond, which ferves as a dam for a corn-mill. By meafuring the time which the water took to rife at a certain height in that pond, he determined the expenditure of water when the corn-mill moved at its common velocity; and alfo when it moved at nearly half that velocity.

The refult of thefe experiments approached very nearly to the former, and all the differences could be accounted for, by a fmall degree of leakage, which took place at the fluices on the lower end of the pond; and the time being greater when the mill moved flower, the leakage would of courfe be greater.

In thefe experiments, the motion of the water-wheel being exactly proportioned to the quantity of water expended, the load upon the wheel muft have been equal when it moved quick or flow, that is to fay, the buckets muft have been equally filled when the wheel moved at its ordinary motion, or at half that motion.

The effect, therefore, of letting more water on a wheel when the refiftance continues the fame, is not to lodge a greater quantity in each of the buckets, but to fupply the fame quantity to each bucket when the wheel is in a greater motion.

The greateft velocity that the circumference of an overfhot wheel can acquire, depends jointly upon the diameter or height of the wheel, and the velocity of falling bodies; for it is plain, that the velocity of the circumference can never be greater, than to defcribe a femicircumference, in the time that a body let fall from the top of the wheel would defcend through its diameter, nor indeed quite fo great; as a body defcending through the fame perpendicular fpace cannot perform its courfe in fo fmall a time, when paffing through a femicircle, as would be done in a perpendicular line. Thus, if a wheel is fixteen feet one inch diameter, a body will fall through the line of its diameter in one fecond: this wheel, therefore, can never arrive at a velocity equal to the making one turn in two feconds. An overfhot wheel can never come near this velocity, for when it acquires a certain fpeed the greateft part of the water is prevented from entering the buckets; and the reft, at a certain point of its defcent, is thrown out again by the centrifugal force. The velocity, when this action will begin to take place, depends in a great degree upon the form of the buckets as well as other circumftances; fo that the utmoft velocity that an overfhot wheel may be capable of is not to be determined generally; and indeed the knowledge of it is not at all neceffary in practice, becaufe a wheel, in fuch cafe, would be incapable of producing any mechanical effect.

V. *On the proper Load for an overfhot Wheel, in order that it may produce a maximum Effect.*—The maximum load or refiftance for an overfhot wheel, is that which will reduce the circumference of the wheel to its proper velocity, of three or three and a half feet *per* fecond; and this will be known, by dividing the effect it ought to produce in a given time, by the fpace intended to be defcribed by the circumference of the wheel in the fame time; the quotient will be the refiftance to be overcome at the circumference of the wheel, and is equal to the load required, the friction and refiftance of the machinery included.

VI. *On the greateft Load that an overfhot Wheel can overcome.*—The greateft load an overfhot wheel can overcome depends upon the magnitude of the buckets; and the refiftance which will ftop the wheel, muft be equal to the effort of all the buckets in one femicircumference, when quite filled with water.

The ftructure of the buckets being given, the quantity of this effort may be affigned, but is not of much importance in practice, as in this cafe alfo, the wheel lofes its power; for though the water makes the utmoft exertion of gravity upon the wheel, yet, being prevented by a counterbalance from moving at all, it is not capable of producing any mechanical effect, according to our definition. An overfhot wheel, generally ceafes to be ufeful before it is loaded to that pitch, for when it meets with fuch a refiftance as to diminifh its velocity to a certain degree, its motion becomes irregular; yet this never happens until the velocity of the circumference is reduced to lefs than two feet *per* fecond, where the refiftance is equable, as appears not only from the preceding fpecimen, but from experiments on larger wheels.

VII. *Conftruction of the Pentrough for fupplying the Water to overfhot Wheels.*—We have hitherto fpoken of the ftream of water, as if it iffued from a fpout nearly in an horizontal direction, or with only fo much inclination as will make the line of the ftream correfpond with the direction of the oblique part of the bucket-board. This is the ancient, and ftill the common way; Mr. Smeaton's, which is a much better, is fhewn in *fig.* 2. *Plate* I. *Water-wheels.* G reprefents the pentrough through which the water flows, and F F ftrong crofs-beams on which it is fupported; the wheel is fituated very clofe beneath the bottom of the trough, as the figure fhews. E E are two arms of the wheel, which are put together, as fhewn in *fig.* 7. D B is the wooden rim of the wheel; the narrow circle beyond this is the fection of the fole planking, and on the outfide of this the bucket-boards are fixed as the figure fhews; one of the bottom boards, *b*, of the trough at the end is inclined, and an opening is left between that end and the other boards of the bottom, to let the water pafs through; this opening is clofed by a fliding fhuttle, *c*, which is fitted to the bottom of the trough, and can be moved backwards and forwards by a rod, *d*, and lever, *e*, which is fixed into a ftrong axis *f*; this axis has a long lever on the end, which, being moved by the miller, draws the fhuttle along the bottom of the trough, and increafes or diminifhes the aperture through which the water iffues. The extreme edge of the fhuttle is cut inclined, to make it correfpond with the inclined part *b*, and by this means it opens a parallel paffage for the water to run through, and this caufes the water to be delivered in a regular and even fheet; and to contribute to this the edges of the aperture where the water quits it, are rendered fharp by iron plates; the fhuttle is made tight where it lies upon the bottom of the trough by leather, fo as to avoid any leakage when the fhuttle is clofed. When the wheel is of confiderable breadth, the weight of the water might bend down the middle of the trough until it touched the wheel; to prevent this, a ftrong beam, O, is placed acrofs the trough, and the trough is fufpended from this by iron bolts which pafs through grooves in the fhuttle, fo that they do not interfere with the motion of the fhuttle.

Fig. 3. of the fame plate is an overfhot wheel, for which Mr. Nouaille took a patent in 1813; he recommends that the water-wheel be made the full height of the fall of water, and that the water be applied upon the wheel at 53 degrees from the vertex. The pentrough is made nearly on the fame plan as Mr. Smeaton's. O R is the trough, *h g* the end inclined in the direction in which the water is intended to be directed, *f* the fhuttle, fliding horizontally on the bottom of the trough, *c d e* the lever for drawing the fhuttle, to which motion is given by a regulating fcrew *a* and nut *b*.

Fig. 9. *Plate* II. *Water-wheels*, is the method of laying on water, which has for feveral years been in common ufe in Yorkfhire and the north of England. In this the water is not applied quite at the top of the wheel, but nearly in the fame pofition as the laft defcribed; but the advantages of this wheel over all others is, that the water can be delivered at a greater or lefs height, according to the height at which the water ftands in the trough; but in all the preceding methods if the water is fubject to variations of height, as all rivers are, then the wheel muft be diminifhed, fo that in the loweft ftate of the water it will ftand a fufficient depth above the orifice in the bottom of the trough to iffue with a velocity rather greater than the motion of the wheel. In this cafe, when the water rifes to its ufual height, or above it, the increafe of fall thus obtained is very little advantage to the wheel; the improved

wheel can at all times take the utmoſt fall of the water, even when its height varies from three to four feet. A A is the pentrough made of caſt-iron; the end of it is formed by a grating of broad flat iron bars, which are inclined in the proper poſition to direct the water through them into the buckets of the wheel. The ſpaces between the bars are ſhut up by a large ſheet of leather, which is made faſt to the bottom of the iron trough at *a*, and is applied againſt the bars; and the preſſure of the water keeps it in cloſe contact with the bars, ſo as to prevent any leakage. This is the real ſhuttle, and to open it ſo as to give the required ſtream of water to the wheel, the upper edge of the leather is wrapped round a ſmaller roller *b*; the pivots at the ends of this roller are received in the lower ends of two racks, which are made to ſlide up and down by the action of two pinions fixed upon a common axis which extends acroſs the trough; this axis being turned, raiſes up or lowers down the roller, and the leather ſhuttle winds upon it as it deſcends, or unwinds from it as it aſcends, ſo as to open more of the ſpaces between the bars, or cloſe them as it is required. In order to make the roller take up the leather, and always draw it tight, a ſtrap of leather is wound round the extreme ends of the rollers, beyond the part where the leather ſhuttle rolls upon it. Theſe ſtraps are carried above water and applied on wheels, which wind them up with a very conſiderable tenſion by the action of a band and weight wrapped on the circumference of a wheel, which is on the end of the axis of thoſe wheels.

The water runs over the upper ſide of the roller, and flows through the ſpaces between the grating into the buckets of the wheel; the deſcent of the water paſſing through the bars, and afterwards in falling before it ſtrikes the bottom of the bucket, is found fully ſufficient to produce the neceſſary velocity of the water, for a fall of four inches produces a velocity of more than four feet *per* ſecond.

We recommend this as the beſt method of applying the water, as we ſee in all other forms that a much greater portion of the fall is given up in order to make the water flow into the wheel; not that any ſuch depth as is commonly given is at all neceſſary, but the aperture in the trough muſt be placed ſo low that the water will run through it in the very loweſt ſtates of the water, otherwiſe the wheel muſt ſtop at ſuch times.

On the Manner of framing Water-wheels.—The weight of every wheel muſt be ſupported by its axis, which therefore demands the firſt conſideration. If the axis is to be of wood it ſhould be made of a tree of hard and durable wood, of a length and ſize proportioned to the ſize and weight of the wheel; into each end a gudgeon or centre ſhould be fixed for the wheel to turn upon. There are two methods of fixing the gudgeon into a wooden axis; one is, by forming the gudgeon with a croſs, which is let into the end of the tree, and faſtened by ſcrews, and the wood is compreſſed round the croſs by two or three iron hoops, fitted on the end of the tree and wedged; this is explained in the article MILL-*Work*. The other method is, to make a ſtrong iron box in a piece with the gudgeon, into which box the end of the tree is received and ſecured by wedges. The box being of an octagon ſhape, and the wood being cut to the ſame figure, it cannot ſlip round within the box.

Of late years it has been uſual to make the great axis of water-wheels of caſt-iron, which is a very good plan, provided the axis is made of ſufficient dimenſions. This was firſt practiſed by Mr. Smeaton, but he was rather unfortunate, as ſeveral of them broke after having been many years in uſe: he then employed hollow tubes of caſt-iron of large dimenſions and conſiderable thickneſs of metal. Even now that the ſtrength of caſt-iron is better underſtood, it is not uncommon for the axis of a water-wheel to break, particularly in cold and froſty weather, and for this reaſon ſome millwrights uſe wrought iron, but the hollow tube is ſo much ſtronger, as to be very ſecure from accident.

In an iron axis it is adviſeable to make the bearings of the axis cloſe to the ſides of the water-wheel, and leave the ends of the axis projecting beyond the bearings, in order to attach the cog-wheel, by which the power of the wheel is to be communicated to other machinery. This diminiſhes the length of the axis between the bearings, and renders it much ſtronger; wooden axes muſt have the gudgeons at the extreme ends.

The next point to be conſidered is, the beſt means of affixing the arms of the wheel firmly to the axis. If the arms are of wood, and the axis alſo, the moſt obvious plan is to mortiſe the arms into the axis; but this is the worſt method that can be adopted, becauſe the axis is much weakened, and the water being admitted into the centre of the tree cauſes it ſoon to decay, nor can an arm be eaſily replaced without taking all the wheel to pieces.

A better way is to uſe eight timbers for the arms, and put them together ſo as to interſect each other at right angles, (as is ſhewn in *fig.* 7. *Plate* I.) leaving a ſquare opening in the centre for the reception of the axis, which is made up to a ſquare by adding pieces of wood to it, and the wheel is faſtened on by wedges. The only objection to this is, that the arms are weakened by interſecting each other, and they ſupport the circular rim of the wheel in unequal ſegments.

In Mr. Buchanan's water-wheel, which we have before deſcribed in *figs.* 4 and 5, *Plate* I. *Water-wheels*, is a particular conſtruction of the arms formed by thin planks of wood. He ſtates that this plan is applicable to any kind of water-wheel; and ſince 1790, when he firſt conſtructed a wheel with arms on that principle, a conſiderable number of large wheels have been erected in Scotland on the ſame plan. It is evident that arms, ſuch as are commonly fixed in mortiſes in the axis, are weakeſt in one direction, and that commonly in the direction of the ſtrain. To remedy this defect the feather-pieces F F are applied all round, having their broadeſt ends towards the centre of the wheel, and being at right angles to the breadth of the principal arms. In order to unite them ſtrongly to the principal arms, and connect the whole more firmly together, a ring of iron, R, is applied on each ſide; blocks of wood being put in the vacant ſpaces between, and the keys or wedges, K K, bind the whole cloſe to the axis.

The very beſt method of uniting the arms to the axis is to have a caſt-iron centre-piece, or ſtrong hoop, to fit on the wooden axis with a broad projecting flanch round it, againſt the flat ſurface of which the arms of the wheel are applied, and the intervals between them filled up by wooden blocks or wedges; the arms and blocks are firmly bound to the iron flanch by iron rings applied to the arms on the oppoſite ſide to the flanch, with ſcrew bolts to go through the whole. This ſame plan is applicable to an iron axis, and will be more clearly underſtood by a reference to the article MILL, and *Plate* XXXIV. *Mechanics;* but it is there deſcribed that the broad circular flanch to ſcrew the arms againſt, is caſt in the ſame piece with the axis. This was Mr. Smeaton's original plan, but the flanch ſhould be made in a ſeparate piece, and faſtened on the axis with wedges; for if caſt in the ſame piece, the contraction of the metal contained in the flanch when cooling, renders the metal of the axis ſpongy at the part where it joins to the flanch, and cauſes them to break at that part. Sometimes the caſt-iron centre-piece is made with a

distinct cell to receive each arm, and they are fastened into the cells by wedges and screw-bolts, but a flat flanch with the intervals filled up by blocks is more simple and secure. Modern wheels are very frequently made with cast-iron arms, which in this case are attached to the axis by a similar centre-piece.

The circular rims of water-wheels are commonly made of wood, put together in two or three thicknesses, the joinings of one ring not coinciding with those of the other, and 8 or 10 segments in each thickness, according to the size of the wheel; the thicknesses are united together by rivets. The arms are attached to the ring by notching them in, and securing them by bolts. Cast-iron rings are now generally used, and with great advantage, because the necessary mortises can be made in iron, without weakening the ring; but the strength of a wooden ring is greatly impaired by the mortises through it.

The number of rings in a wheel depend upon its breadth; when the wheel is four feet wide, two rings will support the float-boards or buckets, but the rings should not be more than five feet asunder, or the floats may bend and yield; for want of a sufficient support each ring is framed with its set of arms, so that every one derives its strength from the axis. When a wheel is of great breadth, the whole will be very much strengthened, by applying oblique braces, extending from the centre-pieces of the outside rings to the circumference of the middle ring, by firmly attaching these oblique braces to the arms of all the rings which they intercept; they form truss-frames which prevent the wheel and the axis from bending by its weight: this is particularly useful in wide overshot wheels.

In breast and undershot wheels the float-boards are nailed to pieces of wood called starts, which are fixed into the mortises in the rings, and project outwards for that purpose.

In overshot-wheels, the rings of the wheels are covered by boards laid parallel to the axis, well jointed together, and spiked down to the rings like the boards of a floor to the joists. This boarding forms a close cylinder, which is called the sole of the wheel, and is the foundation for the buckets. When the rings of the wheel are of iron, holes are left in the castings in the edge of the rings, at regular distances round the circumference, and these are filled up with plugs of wood, into which the nails can be driven to fasten on the boarding of the sole. The sole of the wheel is sometimes made of iron plates rivetted together, and rivetted also to the rings of the wheel.

At the ends of the sole-boards, two circular rings of wood or iron, called shrouds, are fitted on perpendicularly to the sole to form the ends of the buckets; and it is usual, if the wheel is wide, to apply a shrouding over each ring of the wheel, and then the buckets are divided into lengths of about four or five feet. In the flat surfaces of the shroudings, grooves are made for the reception of the ends of the bucket-boards. It is usual to make the first board, which is in the direction of a radius, of wood, and the outside one is generally made of iron plate; but sometimes the whole are made of plate iron, and both parts of the buckets are then bent up out of one piece, and the ends of the plate; and also that part of the edge which is to apply to the sole, is turned square to lie flat against the sole and the shrouding, so that rivets and nails may unite all together, and make water-tight joints.

When the shrouding is of cast-iron, it is made to serve instead of the rings of the wheel, because it has sufficient strength to serve both purposes: the arms of the wheel are in this case applied flat against the ring of shrouding, and bolted to it.

The breast-wheel, *fig.* 3. *Plate* II. *Water-wheels*, at Messrs Strutt's works, which we have already noticed, is deserving of further notice from the manner of putting it together. The rings of the wheel are made of cast-iron, and the float-boards are included between the rings in the manner of an overshot wheel, but the arms are only of wrought iron, being made of small round iron rods, which are very light, and have little strength to resist bending; but as they are all tied in from the centre, the ring cannot deviate from its true circular figure, and to sustain the wheel sideways, oblique bars are extended from the centre-pieces at each end of the axis, and are united to the circular ring in the middle of its breadth, which is 15 feet. We have seen two overshot-wheels of 24 feet diameter, and 9 feet broad, made in the same way. It is plain that in this construction the axis of the wheel can do no office but to support the weight of the wheel; for though these arms are sufficiently strong for that purpose, they can have little strength by way of levers to transmit the force of the circular motion of the rim of the wheel to the axis; but the power is transmitted in a better way than from the axis, *viz.* by a ring of cogs screwed to the circular rim of the wheel, and working in a pinion which conveys the motion to the mill. There is another similar ring of cogs at the other side of the wheel, which works into a pinion fixed on the same shaft, by this means nearly all the strain is taken from the axis of the water-wheel; for the pinion is placed on the descending side of the wheel, so that the weight of the water acting on the float-boards is immediately transmitted to the pinions by the strength of the rings of the wheel.

This method of transmitting the power is also applied to other wheels than those which are made with slight arms like the above; the ring of cogs is sometimes placed in the middle of the breadth of the wheel, and then acts upon one pinion, but it is much better to place it at one side or both sides, if the wheel is very broad, because the circle of the teeth may then be made rather less than the diameter of the rings of the wheel, and the side of the ring being closely fitted to the stone-work of the race, the water may be excluded from the cogs.

It is obvious that of the various constructions of water-wheels, that is the strongest which communicates its motion by means of a ring of cogs immediately attached to its rim, where the power of the water is also applied, the least possible strain being thus thrown on its arms and axis.

The only objection to this plan is, that as the teeth of the cog-wheel are in most cases constantly wet, which prevents the grease from adhering, the usual mode of occasionally greasing the cogs is of little or no use, and the dirt in the water grinds away the teeth; or, were the water even free from dirt, there would be much unnecessary friction and waste of power.

Greasing Machine for the Cog-Wheel of a Water-Wheel.—Mr. Buchanan mentions two water-wheels of this kind, in which the rings of the teeth were wearing very fast, and knowing the trouble and expence of renewing them, he was solicitous to discover some means of rendering them more durable. The only way which presented itself was by some contrivance to keep them well greased.

This he did by a machine shewn in *fig.* 8. *Plate* I. *Water-wheels*; it is nothing more than a kind of pinion, with one or more of its teeth made hollow to contain the greasy substance, and the metal plate of which the hollow cog is composed is perforated with small holes, for exudating the grease through those parts which come in contact with the teeth of the wheel.

Fig. 8. is a section of the greasing machine; A B represents part of the ring of teeth on the circumference of the

water-wheel. The greafing-pinion which works in thefe teeth is mounted on an axis, as is clearly fhewn.

N O a retarding lever, of which N is the fulcrum, and O a weight to make it prefs on the axis of the greafing-pinion, fo as to caufe a refiftance, and make the cogs of the wheel prefs forcibly on the cogs of the pinion.

G H I K, the hollow teeth for containing the greafe; they are made of copper-plate or iron; and to make the perforated fides of the greafing leaves come in clofe contact with the face of the teeth of the wheel, the lever N O, with a fmall weight on it, acts on a pulley fixed on the axle of the pinion, and ferves to retain it.

E F, &c. the folid teeth of the pinion, made of wood; there are fliders which open for admitting the greafe into the hollow teeth at their ends.

The number of leaves in the greafer fhould be fuch, that thofe containing the greafe fhall apply themfelves in the courfe of feveral revolutions of the wheel to each of its teeth. Mr. Buchanan found a greafer of 12 leaves, 4 of which contained greafe, had this effect upon a wheel of 304 teeth; and one of 13 leaves, with one tooth only filled with greafe, ferved a wheel of 168 teeth.

It is beft to ufe a mixture of tallow, oil, and black lead for greafing, made of a confiftency to feed regularly, and frefhened about twice in a week.

Conftruction of a Breaft-Wheel of very great Width.—At Meffrs. Strutt's works is a very powerful breaft-wheel, made of the extraordinary width of 40 feet, and it deferves our notice from the manner of framing it together; its diameter is only 12¼ feet, and it is made without any axis, or rather the axis is hollow, and fo large that the float-boards are fixed immediately upon it. It is made like a very long cafk, 48 feet long, compofed of 32 ftaves of fix inches thicknefs, bound together by hoops like an ordinary cafk; it is five feet in diameter at one end and fix feet at the other, and in the middle 7 feet 2 inches; the fmall end is made up folid for three feet in length, and the gudgeon is fixed in this folid part; the larger end is folid for four feet from the end, and on this part the large cog-wheel is fixed to communicate the motion to the mill; it is 14 feet diameter, and has 120 cogs, whilft the water-wheel is only 12¼ feet diameter to the outfide of the floats. The floats are fupported by 10 circular rings, which are fixed on the outfide of the axis or cafk, at four feet diftance from each other, and the float-boards are fixed between thefe rings, 24 floats being arranged in each circle; but the floats in the different fpaces are not made to line with each other, becaufe if the water was to ftrike upon the whole length of 40 feet of float-board at once, it would give a fenfible fhock to the water-wheel, and work the mill irregularly; hence the floats between all the different rings are placed oppofite to the intervals between the floats in the adjoining fpaces, by which means the water acts on the floats in rapid fucceffion, fo that the ftroke upon any one float is imperceptible.

The float-boards are not made to touch the central-barrel or axis within two inches, in order to leave fpace for the air to efcape. The float-boards in the middle of the wheel are 2 feet 4 inches wide, and at the ends are wider. This wheel has two fhuttles, one above the other, like the breaft-wheel before defcribed in *fig.* 3, and the fame dimenfions; for the wheel is placed in the fame mill, but is adapted to work when the tail-water rifes in time of floods to fuch a height as to prevent the other wheel from working.

A very large overfhot Wheel.—The largeft overfhot water-wheel of which we have heard, is that at Mr. Crawfhaw's iron-works at Cyfarthfa, near Merthyr Tidvil, in South Wales: it is ufed to blow air into three of the large blaft furnaces for fmelting iron; the water-wheel is fifty feet in diameter and fix feet wide: it is chiefly made of caft iron, and has 156 buckets. The axis is a hollow tube, and is ftrengthened by twenty-four pieces of timber applied round it. On each end of the axis is a cog-wheel of twenty-three feet diameter, which turns a pinion. On the axis of thefe are two cranks, and a fly-wheel twenty-two feet diameter, and twelve tons weight; each of the cranks gives motion to a lever, like that of a large fteam-engine, and works the pifton of a blowing cylinder or air-pump 52½ inches in diameter, and five feet ftroke, which blows air into the furnace, both when the pifton goes up and down. The work on the other fide being the fame, it actuates in the whole four of thefe double cylinders; the wheel makes about two and a half turns *per* minute, and each cylinder makes ten ftrokes. It is called Æolus, and was built in 1800 under the direction of Mr. Watkin George.

At Aberdare, in South Wales, is an immenfe double water-wheel, confifting of two wheels of forty feet in diameter, placed one above the other like the figure 8, (fee our article CANAL,) the water from the upper one actuating the lower one, and both being connected together by cog-wheels on their refpective rings. We underftand this machine has not anfwered, and we only mention it as an attempt to occupy a fall of water of eighty feet; in fuch cafes, the *Preffure-engine*, defcribed under that article, is a better method, particularly if the work will admit of a reciprocating motion.

Chain of Buckets.—This is applicable in many fituations where there is a confiderable fall of water. This fketch was taken from one in Scotland ufed to give motion to a thrafhing-mill; the *fig.* 6. *Plate* I. is fo obvious as to need little explanation. The buckets C, D, G, H, &c. muft be connected by feveral chains to avoid the danger of breaking, and united into an endlefs chain, which is extended over two wheels A and B, the upper one being the axis which is to communicate motion to the mill-work; E is the fpout to fupply the water. The principal advantage of this plan is, that no water is loft by running out of the buckets before they arrive at the loweft part, as is the cafe with the wheel. Another is, that the buckets being fufpended over the wheel A of fmall diameter, it may be made to revolve more quickly than a wheel of large diameter, and without increafing the velocity of the defcending buckets beyond what is proper for them. This faves wheel-work when the machine is to be employed, as in a thrafhing machine to produce a rapid motion. On the other hand, the friction of the chain in folding over the wheel at the top, and feizing its cogs, will be very confiderable; thefe cogs muft enter the fpaces in the open links between the buckets, to prevent the chain flipping upon the upper wheel. We think this machine might be much improved by contriving it fo, that the chain would pafs through the centre of gravity of each bucket, whereas in the prefent form, the weight of each bucket tends to give the chain an extra bend.

The *Chain-Pump reverfed* has been propofed as a fubftitute for a water-wheel when the fall is very great, and we think it would anfwer the purpofe with fome chance of fuccefs. It would have an advantage over the chain-pump when employed for raifing water, in the facility of applying cup leathers to the piftons on the chain, in the fame way as other pumps, which leathers expand themfelves to the infide of the barrel, and are kept perfectly tight by the preffure of the water. In the chain-pump fuch leathers cannot be employed, becaufe the edges of the leather-cups would turn down and ftop the motion, when the cups were drawn upwards into the barrel. It is the defective mode of leathering the piftons of the chain-pump which occafions its great friction. In the motion of a machine of this kind

the pistons would descend into the barrel, and might therefore be leathered with cups like other pumps, so as to be quite tight without immoderate friction. This machine was proposed by a Mr. Cooper in 1784, who obtained a patent for it, and Dr. Robison has again proposed it with recommendation.

Mechanism for equalizing the Motion of Water-Wheels.—When a part of the machinery of a mill is suddenly detached from the first mover, or suddenly connected with it, the load of the machine is either increased or diminished; and the moving power remaining the same, an alteration in the velocity of the whole will take place; it will move faster or slower. Every machine has a certain velocity, at which it will work with greater advantage than at any other speed; hence the change of velocity arising from the above cause, is in all cases a disadvantage, and in delicate operations exceedingly hurtful. In the case of a cotton mill, for instance, which is calculated to move the spindles at a certain rate, if from any cause the velocity is much increased, a loss of work immediately takes place, and an increase of waste from the breaking of the threads, &c.; on the other hand, there must be an evident loss from the machinery moving too slow. In steam-engines this evil is remedied by a contrivance called a governor, which we have already described in our article STEAM-*Engine*.

Governors are sometimes applied to water-wheels, and made on various constructions. Smith-bellows have been applied to that use, the upper board rising and falling on any augmentation or diminution of the velocity of the lower board, which received its motion from the mill, and forced air into the space beneath the upper board; from this space the air was permitted to escape by a pipe with a cock. If the lower board worked faster than the air could escape, the upper board would rise, but if it moved slower, then the board would sink; and this rising and falling was applied to regulate the shuttle of the water-wheel, not by the force of the bellows alone, but the bellows were made to throw the wheel-work of the mill into action, either to raise or lower the shuttle.

Of late years a new kind of water-wheel governor has been introduced, the principles of which are nearly the same as the governor of a steam-engine. It has a revolving pendulum, which receives its motion from the mill, and in proportion as the machinery moves faster or slower, the centrifugal force acts with greater or less force upon the balls of the governor, making them approach to, or recede from, the perpendicular axis. This raises or depresses an iron cross, which slides upon the perpendicular axis of the revolving pendulum, and by acting on a lever, is made to engage the sluice with a train of wheel-work, which is kept in constant motion by the power of the water-wheel. When this train is connected with the sluice, it operates upon it so as to enlarge or lessen the passage of the water to the water-wheel, and by augmenting or lessening the quantity of water falling on the wheel, increases or diminishes its speed.

This sluice is made on the principle of the throttle-valve of steam-engines. In order that it may be moved by a small power, it is poised on an axis of motion passing through the middle of the sluice. When it is turned edgeways to the stream of water, it makes no obstruction; but if it is turned perpendicularly, it closes the passage of water, or by placing it more or less obliquely, it alters the area of the passage for the water.

The axis on which the sluice turns, if horizontal, should be one-third of the height of the sluice from the bottom, in order that the pressure of the water above the centre may balance that below.

So long as the machinery is moving at a proper velocity, this wheel-work of the sluice apparatus is not connected with the sluice, and it remains at rest. But if the mill goes too slow, the cross is depressed, and striking the lever in an opposite direction, connects the sluice with a different part or train of wheel-work, which has a motion in a contrary direction to the former, and so produces a contrary effect on the sluice.

The train of wheel-work is so calculated, as to reduce the action on the sluice to a very slow motion, and it is found, from experience, that this is necessary. Where the area of the aperture is too suddenly changed, the effect on the water-wheel would be too violent. See a more complete description of this contrivance in Vol. XXIII. MILL-*Work*.

On the Construction of the Wheel-race and Water-course.—The wheel-race should always be built in a substantial manner with masonry, and if the stones are set in Roman cement, it will be much better than common mortar. The earth behind the masonry should be very solid, and if it is not naturally so, it should be very hard rammed and puddled, to prevent percolation of the water. This applies more particularly to breast-wheels, in which the water of the dam or reservoir is usually immediately behind the wall or breast in which the wheel works, a sloping apron of earth being laid from the wall in the dam to prevent the water leaking. The wall of the breast should have pile planking (see CANAL) driven beneath, to prevent the water from getting beneath, because that might blow up the foundation of the race. The stones of the race are hewn to a mould, and laid in their places with great care; but afterwards when the side walls are finished, and the axis of the wheel placed in its bearings, a gauge is attached to it and swept round in the curve, and by this the breast is dressed smooth, and hewn to an exact arch of a circle: the side walls in like manner are hewn flat and true at the place where the float-boards are to work. It is usual to make the space between the side walls two inches narrower at each side, in the circular part where the floats act, than in the other parts.

In some old mills the breast is made of wood planking, but this method has so little durability that it cannot be recommended. In modern mills, the breast is lined with a cast-iron plate, but we do not approve of this, because it is next to impossible to prevent some small leakage of water through the masonry, and this water being confined behind the iron breast cannot escape, but its hydrostatic pressure to force up the iron is enormous; and if the water can ever insinuate itself behind, the whole surface of the plate rarely fails to break it, if not to blow it up altogether. This is best guarded against by making deep ribs projecting from the back of the plate, and bedding them with great care in the masonry; these not only strengthen the plate, but also cut off the communication of the water, so that it cannot act upon larger surfaces at once, than the strength and weight of the plate can resist. Stone is undoubtedly the best material for a breasting. In overshot-wheels the loss of water, by running out of the buckets as they approach the bottom of the wheel, may be considerably diminished by accurately forming a sweep, or casing round the lower portion of the wheel, so as to prevent the immediate escape of the water, and causing it to act in the manner of a breast-wheel, which has been already described. While this improvement remains in good condition, and the wheel works truly, it produces a very sensible effect; but it is frequently objected to, because a stick or a stone falling into the wheel would be liable to tear off part of its shrouding, and damage the buckets; and again, a hard frost frequently binds all fast, and totally prevents the possibility of working during its conti-

nuance; but we do not think the latter a great objection, for the water is not more liable to freeze there than in the buckets or on the shuttle, and may be prevented by the same means, *viz.* by keeping the wheel always in motion; a very small stream of water left running all night will be sufficient. Mr. Smeaton always used such sweeps, and with very good effect; it is certainly preferable to any intricate work in the form of the buckets.

On setting out Water-courses and Dams.—The most ancient mills were undershot-wheels placed in the current of an open river, the building containing the mill being set upon piles in the river. It would soon be observed that the power of the mill would be greatly increased, if all the water of the river was concentrated to the wheel, by making an obstruction across the river which penned up the water to a required height; and also to form a pool or reservoir of water. A sluice or shuttle would then become necessary to regulate the admission of water to the wheel, and other sluices would be necessary to allow the water to escape in times of floods; for though in ordinary times the water would run over the top of the obstruction or dam, yet a very great body of water running over might carry away the whole work, by washing away the earth at the foot of the dam, and then overturning it into the excavation. This is an accident which frequently happens to mills so situated, and the danger is so obvious, that most water-mills are now removed to the side of the river, and a channel is dug from the river to the mill to supply it with water, and another to return the water from the mill to the river. The difference of level between these two channels is the fall of water to work the mill, and this is kept up by means of a weir or dam entirely across the river; but the water can run freely over this dam in case of floods, without at all affecting the mill, because the entrance to the channel of supply is regulated by sluices and side walls.

The dam should be erected across the river at a broad part, where it will pen up the water so as to form a large pond or reservoir, which is called the mill-pond or dam-head. This reservoir is useful to gather the water which comes down the river in the night, and reserve it for the next day's consumption; or for such mills as do not work incessantly, but which require more water, when they do work, than the ordinary stream of the river can supply in the same time. The larger the surface of the pond is, the more efficient it will be; but depth will not compensate for the want of surface, because as the surface sinks, when the water is drawn off, the fall or descent of the water, and consequently the power of the water, diminishes.

The dam for a large river should be constructed with the utmost solidity; wood framing is very commonly used, but masonry is preferable. Great care must be taken, by driving pile planking under the dam, to intercept all leakage of the water beneath the ground under the dam, as that loosens the earth, and destroys the foundation imperceptibly; when a violent flood may overthrow the whole. It is a common practice to place the dam obliquely across the river, with a view of obtaining a greater length of wall for the water to run over, and consequently prevent its rising to so great a height, in order to give vent to the water of a flood. But this is very objectionable, because the current of water constantly running over the dam, always acts upon the shore or bank of the river at one point, and will in time wear it away, if not prevented by expensive works. This difficulty is obviated, by making the dam in two lengths which meet in an angle >, the vertex pointing up the stream. In this way the currents of water, coming from the two opposite parts of the dam, strike together, and spend their force upon each other, without injuring any part. A still better form is a segment of a circle, which has the additional advantage of strength, because if the abutments at the banks of the river are firm, the whole dam becomes like the arch of a bridge laid down horizontally. This was the form generally used by Mr. Smeaton.

The foot of the dam where the water runs down should be a regular slope, with a curve, so as to lead the water down regularly; and this part should be evenly paved with stone, or planked, to prevent the water from tearing it up, when it moves with a great velocity.

When the fall is considerable, it may be divided into more than one dam; and if the lower dam is made to pen the water upon the foot of the higher dam, then the water running over the higher dam will strike into the water, and lose its force. There is nothing can so soon exhaust the force of rapid currents of water as to fall into other water, because its mechanical force is expended in changing the figure of the water (see *circular weir* in our article CANAL); but when it falls upon stone or wood, its force is not taken away, but only reflected to some other part of the channel, and may be made to act upon such a great extent of surface as to do no very striking injury at any one time, but by degrees it wears away the banks, and requires constant repairs: for it is demonstrable that, as much of the force of the water as is not carried away by the rapid motion with which it flows, after passing the dam, must be expended either in changing the figure of the water, or in washing away the banks, or in the friction of the water running over the bottom.

The cotton-works of Messrs. Strutt at Belper, in Derbyshire, are on a large scale, and the most complete we have ever seen, in their dams and water-works. The mills are turned by the water of the river Derwent, which is very subject to floods. The great weir is a semicircle, built of very substantial masonry, and provided with a pool of water below it, into which the water falls. On one side of the weir are three sluices, each 20 feet wide, which are drawn up in floods, and allow the water to pass sideways into the same pool; and on the opposite side is another such sluice, 12 feet wide. The water is retained in the lower pool by some obstruction which it experiences in running beneath the arches of a bridge; but the principal fall of the water is broken by falling into the water of the pool, beneath the great semicircular weir.

The water which is drawn off from the mill-dam above the weir passes through three sluices, 20 feet wide each, and is then distributed by different channels to the mills, which are situated at the side of the river, and quite secure from all floods. There are six large water-wheels; one of them, which is 40 feet in breadth, we have mentioned, from the ingenuity of its construction; and another which is made in two breadths, of 15 feet each, we have also described. They are all breast-wheels. The iron-works of Messrs. Walker at Rotherham, in Yorkshire, are very good specimens of water-works; as also the Carron works in Scotland.

The largest works for overshot-mills are in Russia, at Colpino, near St. Petersburgh, on the river Neva. They were erected principally under the direction of Mr. Gascoigne of the Carron works in Scotland, and have been greatly improved by the present director, who is an engineer of his school. An immense dam of granite is built across the river to pen up the water, until it makes a large reservoir. The waste and flood waters do not run over this dam, but are conducted out of the reservoir by a semicircular branch of the river, and run over a great weir to join the original course of the river below the works. The

mills are situated in the valley below the great dam, the water being conveyed to the wheels by channels coming through the dam, and conveyed away into a large tail bason, which is the original course of the river. The wheels, which are very numerous, are all 22 feet diameter. They are placed in several different mills, for rolling and forging iron and copper, boring guns, making anchors, &c. These mills are arranged on the sides of the tail bason, which is navigable to bring the boats up to them. There are also two large saw-mills at the end of the semicircular channel.

These works are very complete, owing to the excellent execution of the dam and water-works; but it is not a good plan to place the mills beneath the dam, because if it should fail, or the water pour over it by an extraordinary flood, the mills and buildings below would be in danger of being carried away; whereas, on the other construction, the mills, being placed at a distance from the river, are perfectly safe, and would not be injured if the dam should be wholly carried away. This is not a fault imputable to the gentlemen we have mentioned, as the foundations of these works were commenced in the time of Peter the Great, and too far advanced to admit of altering the plan radically, when the empress Catherine invited Mr. Gascoigne to Russia, in 1786, to enlarge them to their present magnitude.

On the Distribution of the different Falls of Water in Rivers.—In erecting a mill, care must be taken to place it so that it shall not be impeded by flood-waters, except when they rise to excess. When the water below will not run off freely, but stands penned up in the wheel-race, so that the wheel must work or row in it, the wheel is said to be tailed, or to be in back water or tail water.

Upon most rivers in this country all the falls of water are fully occupied, and at every mill there is a weir, which pens up the water as high as the mill above can suffer it to stand without inconvenience. Each miller is anxious to obtain the greatest possible fall, and he can at any time augment the fall, by raising the surface of his weir; but as this may produce an inconvenience to the mill above, in preventing the water from running freely away from its wheel, it is a constant source of dispute and litigation. A mill may be subjected to tail-water by the concurrence of so many circumstances, that it is frequently very difficult to know where to seek the best remedy, whether the miller ought to raise his wheel higher and diminish his own fall, or insist upon a diminution of his neighbour's below him by lowering his weir.

The following rule is that which Mr. Smeaton constantly followed, in placing successive dams upon rivers, whether for the erection of mills or for navigation. In flat countries, where the falls of water are small, and consequently tail or back water is most troublesome, those dams must be so built, that no one shall pen the water into the wheel-race of the mill next above it, when the river is in its ordinary summer's state. The same rule we have found generally subsisting in ancient mills.

This rule is founded upon reason; for if the erection of a dam does not affect the mill above by tail-water, in dry seasons, when water is the most scarce, it can do no material injury at any other time. Every mill that is well and properly constructed will clear itself of a considerable depth of tail-water, provided it has at the time an increase of the height of water in the mill-dam or head, and an unlimited quantity of water to draw upon the wheel; for if floods produce tail-water, they also increase the head water, and afford a superior quantity to be expended. This is the proper means by which a number of mills on the same river are to be cleared of back-water, as far as is consistent with the mutual enjoyment of their several falls of water. This alone is a very sufficient security against any one being injured. Common breast-mills will bear two feet of tail-water, when there is an increase of head, and plenty of water to be drawn upon the wheel, without prejudice to their performance; but mills well constructed, with slow moving wheels, will bear three and even four feet and upwards of tail-water. Mr. Smeaton mentions having seen an instance of six feet; and it is a common thing in level countries, where tail-water is most annoying, to lay the wheels from six to twelve inches below the water's level of the pond below, in order to increase the fall of water; and, if judiciously applied, is attended with good effect, as it increases the diameter of the wheel, and though it must always work in that depth of tail-water, it will perform full as well, because the water ought always to run off from the bottom of the wheel, in the same direction as the wheel turns.

The law respecting mill property is by no means settled, but is greatly influenced by the custom of the mills upon any river or in any district; some few points however are established. Every one has a right to that fall which the water has, in running through his own grounds, and may make what use he pleases of the descent of the water, provided that he does not divert the water, at the tail of his estate, into any other channel, or that he does not pen up the water higher than the level at which it has always entered into his land; he has also a right to insist that the miller below shall let the water depart from his grounds, at the same level at which it has always been used to do. The knowledge of this is very necessary, because a miller very frequently finds himself seriously injured, when he is not entitled to any redress. It scarcely ever happens that any considerable improvements or alteration in mills can be made, without producing disputes among the parties interested. Suppose, for instance, that there are two ancient mills upon a river, with an unoccupied descent in running over the lands between them, the proprietor of this land, by deepening the channel and erecting a weir, may bring all the fall into one place and erect a mill, without infringing the conditions we have laid down; but still the miller below him may be considerably injured: for in the original state the river, in running down with a regular and easy slope, from the upper mill to the lower, held a great quantity of water, which was a *corps de reserve* for the miller below, and tended to regulate his supply. If the upper mill stopped working, the water contained in the river would still run down to him, and so long as that lasted he could continue to work, perhaps until the upper mill began to work again, and thus he would suffer no interruption. The erection of an intermediate mill cuts off this resource, and he will be obliged to stop working very soon after the new mill stops working; and further, he is obliged to work when the new mill is at work, or else the water poured down will run over his mill-dam and be wasted; but, in the former instance, the water would have come down less suddenly, and he might be able to set to work before the whole of the water had escaped over his weir.

In such a case the lower miller may be inclined to appeal to the law, but he will find that he has no right to prevent his neighbour above from using the water in the same manner as he does himself, and if he finds any alteration in his own mill, it is for want of a capacious mill-pond to reserve the water. In the original state the channel of the river in his neighbour's ground above served him in some measure as a mill-dam, by retaining the water for a given time, though it would not retain it permanently. The advantage of this he had enjoyed for a long time, when it was no inconvenience to his neighbour, but had acquired no right to

demand that his neighbour's property ſhould be ſacrificed for his convenience, but he muſt relieve himſelf by making an artificial pond for his own mill.

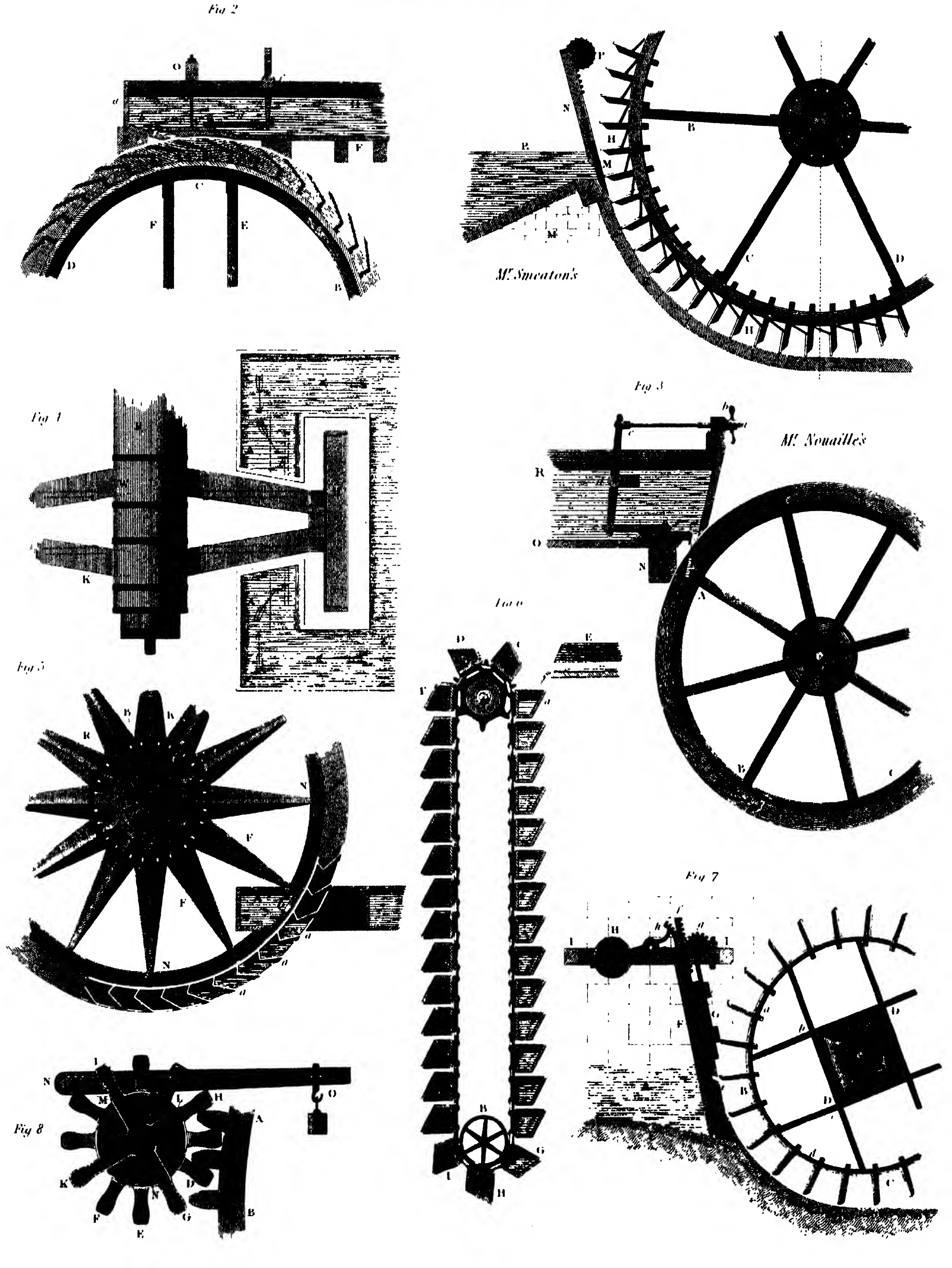
The ſame queſtion ariſes when any mill is altered or enlarged, ſo as to conſume the water faſter than the river brings it down, for ſuch a mill can only work for ſhort intervals, and muſt then ſtop that the water may accumulate in the dam until there is a ſufficient quantity to ſet to work again. This is the ſyſtem of copper-mills and rolling-mills, for during the time that the iron or copper is heating in the furnace, the mill is ſtopped, and the water gathered in the dam; but when the metal is ready, it is ſet to work with all the power of the water penned up. This is very prejudicial to a mill below, particularly if it is a corn-mill, which cannot conſume the water faſter than the regular ſupply of the river, and ſometimes alſo to mills above by frequently tailing their water.

Much uſeful information on theſe points will be found in Smeaton's Reports, 3 vols. 4to. 1813.

WATER WHEELS.

PLATE I.

OVER SHOT and UNDER SHOT.



C. Varley del.   Published as the Act directs, 1817 by Longman, Hurst Rees, Orme, & Brown, Paternoster Row, London.   Lowry sculp.

Breast WHEEL with two Shuttles.

Fig 3

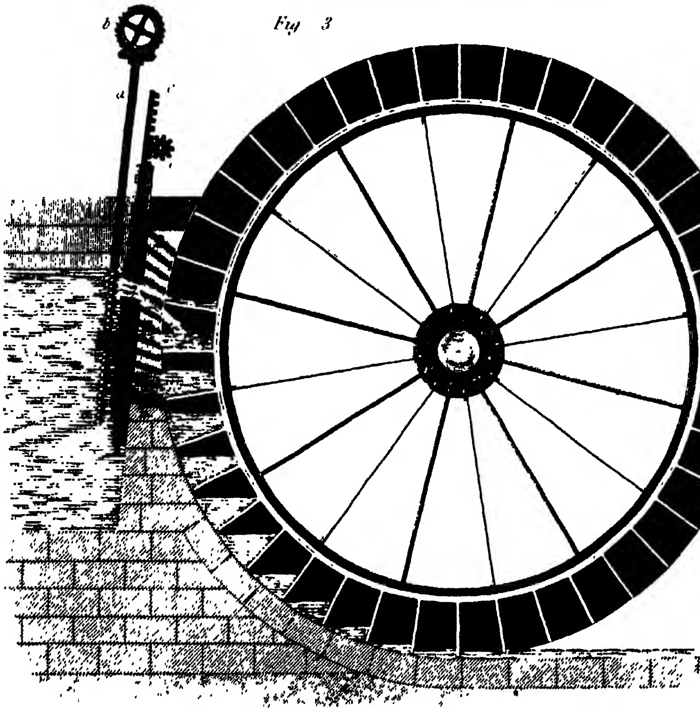
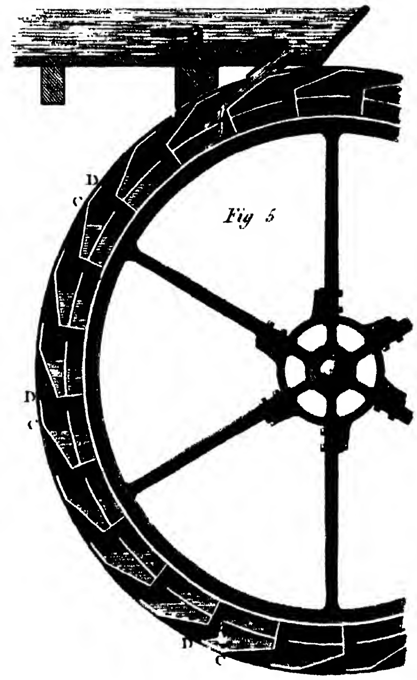
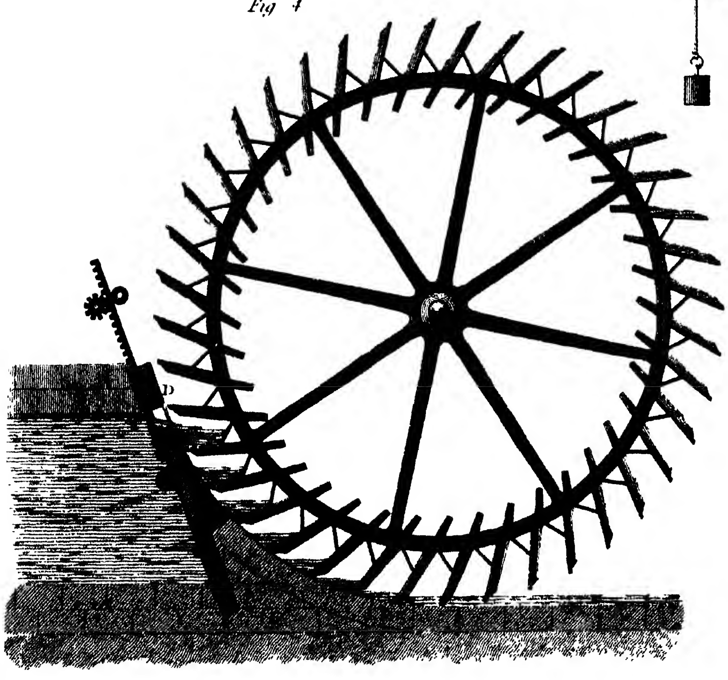


Fig 5



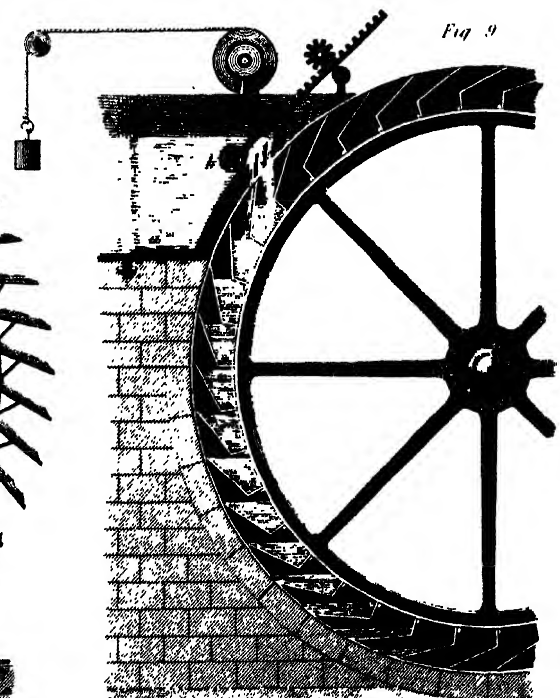
Breast WHEEL in which the water flows over the Shuttle

Fig 4



Overshot WHEEL

Fig 9



J Farey, delin. Published as the Act directs, 1819, by Longman, Hurst, Rees, Orme & Brown, Paternoster Row Lowry, Sc.

WAX, a term which comprehends two or three fubftances, differing in their nature and origin, and yet poffeffing feveral common properties. The common properties of the animal and vegetable productions, of which we fhall give a brief account in the fequel of this article, are fufibility at a moderate heat; when kindled, burning with much flame; infolubility in water; folubility in alkalies, and alfo in alcohol and ether; in which two latter properties all the fpecies of wax differ from the concrete oils, to which in other refpects they bear a very ftrong refemblance. The moft important, and moft generally known and ufed of thefe fubftances, is

Bees'-wax, excreted from the body of the bee, and employed by thefe infects in the conftruction of their cells, both for the accommodation of their young and the depofition of their honey. Of this fubftance, a young hive will yield at the end of the feafon about a pound of wax; and an old hive about twice as much. The fineft wax is that which is made in dry, heathy, or hilly countries; but in parts abounding with vineyards it is decidedly inferior. Although the commonly received notion, which afcribes this fubftance to the elaboration of the pollen of flowers, which the bees vifibly collect on their thighs, had received the fanction of obfervers not lefs diftinguifhed than Bonnet and Reaumur (fee PAIN *D'Abeilles*), yet the Lufatian Society, as long ago as the year 1768, was not unacquainted with the fact, that the wax, inftead of being difcharged from the mouth, is fecreted in the form of thin fcales among the abdominal rings or fegments. In 1792, the celebrated Mr. John Hunter detected the genuine refervoir of the wax under the belly of the bees, and gave an account of his obfervations in the Philofophical Tranfactions, (vol. lxxxii. part 1.) On elevating the lower fegments, he obferved plates of a fufible fubftance, which he afcertained to be wax; and he was convinced, that an effential difference fubfifts between the pollen, which thefe little creatures collect with fo much care and induftry in the form of pellets on their thighs, and the matter of which the combs are conftructed. This curious fubject has been further inveftigated by Meffrs. Huber, father and fon; and they have demonftrated the organs in which the wax is fecreted, though they had eluded the perfpicuity of Swammerdam, Hunter, and other acute anatomifts. Thefe facklets, or fmall compartments, now minutely explained and illuftrated by engravings, are peculiar to the working bees, which alone produce wax; and each individual is furnifhed with eight of them. The waxy matter, as it occurs in a tranfuded ftate in the fecretory organs, differs from the frefh wax of the combs only in being of a lefs compounded nature, which has been afcertained by trials with fpirit of turpentine and fulphuric ether. Profecuting thefe reflections, our ingenious authors concluded that the common opinion was probably erroneous; becaufe, like Hunter, they had obferved fwarms, newly placed in the empty hives, conftruct their combs without fetching home any pollen; while the bees of old hives, where no frefh cells were required, neverthelefs provided an ample ftock of this powder. In order, however, to determine the point more directly, they confined a recent fwarm within an empty ftraw-hive, leaving at their difpofal only a fufficiency of honey and water for their confumption, and preventing them from going beyond the precincts of a well-clofed room; when, in the fhort fpace of five days, they had conftructed five cakes of a beautiful white though very fragile wax. This experiment was repeated, and was uniformly accompanied by fimilar refults; and therefore they no longer hefitated in admitting the fact, that honey, through the organic intervention of bees, may be converted into wax. In order to determine whether vegetable pollen, alfo, was fufceptible of this converfion, the honey was wholly removed, and the confined bees were fed on fruits and pollen, of which laft a large ftore was left at their difpofal; but, though they continued in this fituation during eight days, they neither made any wax, nor exhibited any plates under their abdominal rings. Having fufpected that the fecretion of wax originated in the cohefive principle contained in honey, our authors recurred to various experiments, which conftantly proved that fugar alone was an excellent fubftitute for honey, and, on fome occafions, afforded a fuperior wax. They afterwards found, that bees, when left at perfect liberty to roam abroad, act precifely on the fame principle in the conftruction of their combs; and they alfo difcovered, that labourers of two defcriptions exift in each hive. The firft, fufceptible of acquiring confiderable dimenfions, when they have received all the honey which their ftomachs can contain, are principally deftined to the elaboration of the wax; while the fecond, whofe abdomen undergoes no fenfible change of bulk, neither gather nor retain more honey than is neceffary for immediate fubfiftence, and readily fhare that which they collect with their companions; who take no charge of ftoring the hive with provifions, their appropriate office being to attend the young. Thefe they call nurfing or fmall bees, in contradiftinction to thofe with dilated bellies, and which, as they fay, are entitled to the appellation of "wax-workers." The exiftence and feparate offices of thefe two forts of bees were fufficiently afcertained. When the hives are filled with combs, the wax-working bees difgorge their honey into the ufual magazines, and produce no more wax; but, if they have no receptacle in which they can depofit it, and if the queen finds no cells formed ready for the reception of her ova, they retain in their ftomachs the honey which they had amaffed; and, at the end of 24 hours, the wax oozes out between the rings, when the fabrication of the combs commences. The nurfing bees alfo produce wax, but in a much fmaller quantity than the others.

As for the ufe of the pollen, our authors have afcertained, that it is collected for the purpofe of feeding the young; and they have alfo found, that bees, fed too long on the fyrup of fugar alone, are incapable of rearing their offspring, and at length defert the hive. The waxy matter, when newly fecreted and moulded in its appropriate organs, differs from real wax in being tranfparent like fcales of talc, white, and quite friable, or brittle; whereas that of which the cells are compofed is of a yellowifh-white, opaque, and flexible. Our limits will not allow our defcribing the procefs obferved by our authors with the aid of a glafs apparatus, by which thefe infects commence and conduct the conftruction of their combs. The difference of afpect and confiftency between cells juft formed, and thofe which are of older ftanding, cannot fail to attract the attention of every obfervant apiarian. The former are, in fact, of a dull white colour, femi-tranfparent, foft, and even, without being fmooth; but, in the courfe of a few days, the whole of their internal furface affumes a yellow tint of greater or lefs intenfity: their fharp edges become thicker and lefs regular; and thofe tubes, which at firft could not refift the flighteft preffure, become flexible, fomewhat more heavy, and more difficult of folution in hot water. The contour of the orifice of mature cells is bound with a rim of a reddifh and odorous refin, which is alfo employed to cement the angles of other parts of the cell. This folder or varnifh is found, on chemical trial, to be identical with the propolis,

and quite diſtinct from the wax. Meſſrs. Huber have not only eſtabliſhed this important fact, but detected the origin of the propolis itſelf. Having obtained branches of the wild poplar, cut in ſpring before the developement of their leaves, with very large buds filled with viſcous, reddiſh, and odorous juice, they placed theſe in the way of the bees to the fields, ſo that they muſt ſee them: ſoon after this arrangement, a bee alighted on one of the branches, and approached one of the largeſt buds; ſhe then ſeparated its folds with her teeth, attacked the parts which ſhe had half-opened, pulled off filaments of the viſcid matter with which they were filled, and then ſeized, with one of the legs of the ſecond pair, the ſubſtance held between her jaws, brought forwards one of her hind-legs, and finally placed in the baſket of that leg the little ball of propolis which ſhe had juſt collected. Having accompliſhed this object, ſhe again opened the bud in another place, carried off new threads of the ſame matter with her teeth, laid hold of them with the legs of the ſecond pair, and placed them nicely on the other baſket. She then took her departure, and rejoined her hive. In a few minutes afterwards, a ſecond bee alighted on the ſame branches, and loaded herſelf with propolis in the ſame manner. This propolis was found to be different from the matter which imparts the yellow colour to the wax, which is probably ſecreted in the cavity of the teeth, and depoſited on the wax. We obſerve, however, that bees are not contented with merely painting and varniſhing their cells, but they alſo impart additional ſolidity to their aggregate amount by the uſe of a mortar, compoſed of wax and propolis; and which the ancients, who had not overlooked this department of their economy, termed *metis*, or *piſſocerum*. (See PROPOLIS.) With the neceſſary documents before us, we cannot forbear introducing ſome further obſervations on the economy of theſe inſects, though they are not immediately connected with the ſubject of this article. As the cloſeneſs of a hive, and the multitude of living creatures which inhabit it, (amounting ſometimes to twenty-five or thirty thouſand,) are circumſtances which ſeem to preclude a free ventilation and renewal of air, we might be induced to ſuppoſe that bees are not endowed with any particular ſyſtem of reſpiratory organs, and that they are capable of exiſting in any atmoſphere, however vitiated. As a teſt of this ſuppoſition, our ingenious and perſevering authors recurred to various experiments; which inconteſtibly prove, that theſe inſects cannot long exiſt either in *vacuo*, or in air that is contaminated by noxious gaſes; that, in ſhort, they breathe like other animals of their claſs; and that they are ſpeedily deprived of life if the proceſs of reſpiration be arreſted. Yet it reſults, from eudiometrical trials, that the air of a well-ſtocked hive is equally pure with that of the atmoſphere. It has been aſcertained, too, that neither wax nor pollen favours the production of oxygen gas, and that the bees themſelves have no internal faculty of generating vital air; ſince, if that of the atmoſphere be entirely excluded, they are obſerved to periſh in the courſe of a few hours. Our authors, therefore, took an opportunity of examining, whether the induſtry of theſe inſects preſented no particular cauſe of this phenomenon; and at length they were ſtruck by the connection which might ſubſiſt between the circulation of the air and that beating of the wings which they had recently obſerved, and which occaſioned a continual humming in the interior of their habitation. They ſuſpected that the play of theſe membranes, which impreſs the air with ſufficient force to elicit from it a very diſtinct ſound, might be deſtined to replace that which had been vitiated by reſpiration. Although this may ſeem to be a trivial cauſe for counteracting the pernicious effect above ſtated, yet by putting the hand near to a fanning-bee, we ſhall perceive that ſhe agitates the air in a manner that is very ſenſible, and moves her wings with ſuch rapidity as that they are ſcarcely diſtinguiſhable.

United at their edge by means of ſmall hooks, the two wings of each ſide preſent a larger ſurface to the air, on which they have to ſtrike; they form, beſides, a ſlight concavity, which ſhould ſomewhat contribute to increaſe their energy; and we may be ſatisfied that they deſcribe an arc of 90°, becauſe we ſee them, ſimultaneouſly, on the two extremes of their vibrations. When engaged in this exerciſe, the bees cling faſt to the ſtand with their legs, the firſt pair being projected forwards, the ſecond ſeparated and fixed to the right and left of the body, while the third, cloſely approximated, and in a direction perpendicular to the abdomen, contributes to ſupport the hinder parts in an elevated poſition. During the fine ſeaſon, we may always obſerve a certain number of bees agitating their wings in front of the entrance to their hive; but we may alſo be convinced, by inſpection, that ſtill more of them are employed in fanning within their dwelling. The ordinary ſtation of the ventilating bees is on the lower floor of the hive. All thoſe which are occupied in this way, on the outſide, have their heads turned towards the entrance, but thoſe within preſent their backs to it. Theſe bees ſeem to arrange themſelves methodically, ſo that they may manage the ventilating proceſs with the greateſt eaſe; being diſtributed into files, which terminate at the entrance of the hive, and are ſometimes diſpoſed like ſo many diverging rays; but this order is not uniform: and it is probably owing to the neceſſity to which the fanning bees are ſubjected of leaving room for ſuch as go and come, whoſe rapid courſe conſtrains them to form in file, that they may avoid being joſtled and overturned at every inſtant. More than 20 bees may ſometimes be ſeen ventilating in the lower part of the hive; but their number at other times is ſmaller; and each of them vibrates her wings for a longer or ſhorter period. They have been obſerved to continue the exertion during 25 minutes, without reſting; although they ſeemed occaſionally to take breath by ſuſpending the vibration of their wings for an almoſt imperceptible inſtant; but, as ſoon as they ceaſe from fanning, others take their place, ſo that the humming noiſe in a well-filled hive never ſuffers interruption.

But to return from this digreſſion to the principal ſubject of the article.

Bees'-wax makes a very conſiderable article in commerce; the conſumption of it throughout the ſeveral parts of Europe being incredible. There are two kinds, *white* and *yellow;* the yellow is the native wax, juſt as it comes out of the hive, after expreſſing the honey, &c. This colour, ſays Thorley, is owing to the age of the combs, and breath of the bees; wax, he ſays, both as it is gathered, and wrought into combs, being always white: the white is the ſame wax, only purified, waſhed, and expoſed to the air. The preparation of each follows.

WAX, *Yellow*. To procure the wax from the combs for uſe; after ſeparating the honey from them as much as poſſible by the preſs, they are either ſoaked for ſome days in clear water, in order to extract all the honey, or they are broken into pieces, and ſpread on a ſheet near the hives, ſo that the bees in time ſuck out all the honey that is left, and reduce the wax into ſmall fragments like bran. Then the whole of the wax is put into a large kettle, with a ſufficient quantity of water; and with a moderate fire, it is melted, and then ſtrained through a linen cloth, by a preſs, and thus freed from all remaining impurity. Before it is cold, they ſcum it with a tile, or a piece of wet wood, and caſt it,

while yet warm, in wooden, earthen, or metalline moulds; having firſt anointed them with honey, oil, or water, to prevent the wax from ſticking. Some, to purify it, make uſe of Roman vitriol, or copperas; but the true ſecret is to melt, ſcum it, &c. properly, without any ingredients at all.

The beſt is that of a high colour, an agreeable ſmell, ſomewhat reſembling that of honey, ſoft, ſomewhat unctuous to the touch, but not ſticking to the fingers, nor to the teeth when chewed. When new, it is of a lively yellow colour; it is ſomewhat tough, yet eaſy to break; by age, it loſes its fine colour, and becomes harder and more brittle. In winter it becomes conſiderably hard and tough. It is deprived of its yellow colour and ſmell by expoſing it in thin laminæ to the action of the light and air, in the proceſs of bleaching; by which it becomes perfectly white, ſcentleſs, ſomewhat harder, and leſs greaſy to the touch. However, wax is often ſophiſticated with reſin, or pitch, coloured rocou, or turmeric.

The preſence of reſin may be ſuſpected when the fracture appears ſmooth and ſhining, inſtead of being granulated: and it may be ſaturated by putting ſmall pieces of the wax into cold alcohol, which will readily diſſolve the reſinous part, without affecting the wax in any conſiderable degree.

Its adulteration with earth or peas meal may be ſuſpected when the cake is very brittle, and the colour inclining more to grey than bright pale yellow; and they may be ſeparated by ſmelting and ſtraining the wax. White wax is ſometimes adulterated with white oxyd of lead, in order to increaſe its weight. This may be known by melting the wax in water, when the oxyd falls to the bottom of the veſſel.

It is alſo adulterated by tallow, ſuet, or any kind of animal fat. It then becomes more fuſible, and when rebleached and expoſed to a hot ſun, it is very apt to cake. It likewiſe loſes its ſemi-tranſparency, the diſtinguiſhing property of pure bleached wax. This adulteration may be detected by boiling alcohol, which will diſſolve wax, but not tallow.

Wax, *White*. The whitening, blanching, or bleaching of wax, is performed by reducing the yellow ſort, firſt, into little bits or grains, and melting it in a copper cauldron, with water juſt ſufficient to prevent the wax from burning. The cauldron in which the wax is melted is ſo diſpoſed, that it may flow gradually through a pipe at the bottom into a large tub filled with water, and covered with a thick cloth, to preſerve the heat till the water and impurities are ſettled. From this tub the clear melted wax flows into a veſſel, the bottom of which is full of ſmall holes, about the ſize of a grain of wheat, and hence it falls in ſmall ſtreams upon a cylinder, conſtantly revolving over water, into which it occaſionally dips, ſo that the wax is cooled, and at the ſame time drawn out into thin ſhreds or ribbands. The continual rotation of the cylinder carries off theſe ribbands as faſt as they are formed, and diſtributes them through the tub. The wax, thus granulated or flatted, is expoſed to the air on linen cloths, ſtretched on large frames, about a foot or two above the ground, in which ſituation it remains night and day for ſeveral days, expoſed to the air and ſun; and thus the yellow colour nearly diſappears. In this half-bleached ſtate, it is heaped up in a ſolid maſs, and allowed to remain for a month or ſix weeks; after which, to complete the proceſs for whitening it, it is re-melted, and ribbanded, and bleached as before, (in ſome caſes ſeveral times) till it wholly loſes its colour and ſmell. Some manufacturers, in re-melting it, add alum or cream of tartar, which are ſuppoſed to increaſe the whiteneſs and ſolidity of the wax. Some alſo, inſtead of ſpreading the ribbands of wax on cloths, lay evenly a broad courſe of bricks, which are frequently watered, ſo that the wax is kept from melting by the ſun's heat abſorbed by the bricks.

When the ſun and air have at length perfectly blanched the wax, ſome melt it for the laſt time in a large kettle; out of which they caſt it, with a ladle, upon a table, covered over with little round dents or cavities, of the form of the cakes of white wax, as ſold by the apothecaries, &c. having firſt wetted thoſe moulds with cold water, that the wax may be the more eaſily got out. Laſtly, they lay out theſe cakes to the air for two days and two nights, to render it more tranſparent and dry.

As the volatile ſulphureous acid has the property of deſtroying more quickly almoſt all the colours of vegetables, it has been ſuggeſted by Macquer, the author of the Chemical Dictionary, that this bleaching might perhaps be ſhortened, by expoſing ribbands of yellow wax to the vapour of ſulphur, as is practiſed for wool and ſilk; but this proceſs has not been found to ſucceed.

However, the operation of bleaching wax above deſcribed can be performed well only in fine weather, as it depends chiefly on the action of the ſun. This circumſtance being attended with much inconvenience to the manufacturers, the diſcovery of a method of whitening wax independently of the ſeaſons would be very uſeful, and has been recommended to the attention of chemiſts by ſome economical ſocieties.

With a view to diſcover ſuch a method, Mr. Beckman has made experiments, an account of which is publiſhed in the fifth volume of the "Novi Commentarii Societatis Regiæ Scientiarum Gottingenſis." According to theſe experiments, thin pieces of yellow wax were whitened and hardened, by being digeſted and boiled in diluted and undiluted nitrous acid, in a few hours. But the wax thus whitened, being melted by means of boiling water, was obſerved to acquire a yellow colour, leſs intenſe, however, than it was before it had been treated with the mineral acids. The marine and vitriolic acids were leſs effectual than the nitric or nitro-muriatic. He expoſed wax to the flames of burning ſulphur, but without ſucceſs. Yellow wax being melted in vinegar, was rendered of a grey colour. The oil of tartar whitened wax, but leſs effectually than acids had done; and this wax being waſhed in water, and afterwards digeſted in nitrous acid, was rendered ſtill more white; but upon melting it in water, a yellowiſh tinge returned. He liquefied wax in ſolutions of nitre and alum, but without any good effect. Spirit of wine, which is recommended by Mr. Boyle for this purpoſe, did indeed whiten the wax, but changed it to a butyraceous ſubſtance, ſo frothy, that its bulk was increaſed thirty times. Reflecting that tartar is purified from its oily particles by means of a calcareous earth, he tried the effects of a kind of fuller's earth, which he threw upon wax liquefied in water, and he agitated the mixture. This method rendered wax of a greyiſh colour, and is, therefore, recommended by him as preparatory to bleaching; the time neceſſary for which, he thinks, may be thus greatly ſhortened.

M. Sennebier made ſome remarks on the effect of light, and other ſuppoſed diſcolouring agents. Some yellow wax was melted, and thinly ſpread upon a plate of glaſs; and a ſimilar plate was laid upon it when hot; and the edges of the plates were cloſed with ſealing-wax. Thus the bees'-wax was deprived of the acceſs of air, and it was placed in the ſun, to the light of which it was expoſed for four or five hours daily. Another quantity of wax was incloſed between plates in a like manner, but kept in the dark. In two days the wax expoſed to the ſun began to bleach, and

in a month's time the whole, when it did not exceed one-fixth of an inch in thicknefs, was quite white; whilft no change at all took place in that which was kept in darknefs.

Alcohol has no fenfible action on wax when cold, but if the fluid be boiled, it will diffolve rather lefs than one-twentieth of its weight of wax; and the greater part of it feparates, when cold, in the form of white bulky flocculi, while the fmall quantity that remains is wholly precipitated by water. Such is the refult of Pearfon's and Boftock's experiments; whereas Fourcroy, Chaptal, and Nicholfon affert, that it is infoluble in this fluid. Sulphuric ether diffolves wax when heated, and much more copioufly than alcohol diffolves it, but the greater part, like that of the former, is feparated by cooling, and the remainder by water. Wax boiled in cauftic potafh makes the fluid turbid, and in procefs of time rifes to the furface in a flocculent form. The portion of the wax, held in folution by the clear alkaline liquor, may be feparated by an acid, and the refidue floating on the furface is fo far converted into a faponaceous ftate as to have loft its inflammability, and to be no lefs foluble in pure water than white foap, and again precipitable by acids nearly in its original form, with a reftoration of its inflammability. Pure ammonia nearly refembles the fixed alkalies in its action; but the refulting faponaceous form is lefs foluble in water.

When yellow wax has been long fwimming in a folution of carbonate of potafh, it becomes grey; and this colour is entirely changed into a milk white by fubfequent digeftion in nitric acid, and the wax refumes its whitenefs.

If wax be diftilled with a heat greater than that of boiling water, it may be decompofed. By this diftillation, a fmall quantity of water is firft feparated from the wax, and then fome very volatile and penetrating acid, (probably a modification of the acetous,) accompanied with a fmall quantity of a very fluid and very odoriferous oil. As the diftillation advances, the acid becomes more and more ftrong, and the oil more and more thick, till its confiftence be fuch, that it becomes folid in the receiver, and is then called *butter of wax*. When the diftillation is finifhed, nothing remains but a fmall quantity of coal, which is almoft incombuftible, from the want of fome faline matter. Wax cannot be kindled, unlefs it be previoufly heated, and reduced into vapours; in which refpect it refembles fat oils. The oil and butter of wax may, by repeated diftillations, be attenuated, and rendered more and more fluid, becaufe fome portion of acid is thereby feparated from thefe fubftances; which effect is fimilar to what happens in the diftillation of other oils and oily concretes; but this remarkable effect attends the repeated diftillation of oil and butter of wax, that they become more and more foluble in fpirit of wine; and that they never acquire greater confiftence by the evaporation of their more fluid parts. Boerhaave kept butter of wax in a glafs veffel open, or carelefsly clofed, during twenty years, without acquiring a more folid confiftence. Wax, its butter, and its oil, differ entirely from effential oils and refins, in all the above-mentioned properties; and in all thefe perfectly refemble fweet oils. Hence Macquer concludes, that wax only refembles refins in being an oil rendered concrete by an acid; but that it differs effentially from thefe in the kind of oil, which in refins is of the nature of effential oils; while in wax and other analogous oily concretions, it is of the nature of fweet, unctuous oils, that are not aromatic, and not volatile, and are not obtained from vegetables by expreffion.

Although wax is not diffoluble at all in watery liquors, yet the gelatinous folution obtained by boiling it in fpirit of wine, by mixture with a thick mucilage of gum arabic, becomes foluble in water, fo as to form therewith an emulfion or milky liquor: the wax itfelf is made in like manner foluble, without the intervention of fpirit, by thoroughly mixing it with the gum in fine powder; but when thus diffolved, it proves ftill infipid, and perfectly void of acrimony.

Wax is foluble abundantly in the fixed oils, and melted with them, produces an uniform mafs, the confiftence of which, whatever be the proportion of each, is intermediate between the two. It is diffolved but fparingly in effential oils.

Bleached wax burns with a very pure white light, without any offenfive fmell, and with much lefs fmoke than tallow; and as it is lefs fufible than tallow, it requires a fmaller wick. (See CANDLES.) Bleached wax melts at about 155° of Fahrenheit; and the unbleached at 142°, according to Pearfon and Nicholfon, and alfo Dr. Boftock, but at 117° according to Fourcroy; whilft tallow melts at 92°, fpermaceti at 133°, adipocire at 127°, and the pela of the Chinefe at 145°. (See Nicholfon's Journal, vol. i. p. 70, 4to.) The fpecific gravity is lefs than that of water, being about .96.

The *yellow* wax is brought to market in round cakes about two inches thick; and large quantities of it are imported, from the Baltic, the Levant, and the Barbary coaft.

The *white* wax is ufed in the manufacture of candles, torches, tapers, figures, and a variety of other wax-works. See CANDLES, &c.

It is alfo an article of the *Materia Medica*, and ufed as an ingredient, partly for giving the requifite confiftence to other ingredients, and partly on account of its own emollient quality, in plafters, cerates, and divers pomatums and unguents for the complexion.

The yellow fort, diffolved into an emulfion, or mixed with fpermaceti, oil of almonds, conferve of rofes, &c. into the form of an electuary; or divided, by ftirring into it, when melted over a gentle fire, as much as it will take up of powdery matter, as the compound crab's-claw powder, has been given alfo internally, and, as fome have pretended, often with great fuccefs, in diarrhœas and dyfenteries, for obtunding the acrimony of the humours, fupplying the natural mucus of the inteftines, and healing their excoriations or erofions.

The empyreumatic oil, into which wax is refolved by diftillation with a ftrong heat, is greatly recommended by Boerhaave and others, for healing chaps and roughnefs of the fkin, for difcuffing chilblains, and with proper fomentations and exercife, againft ftiffnefs of the joints, and contractions of the tendons. It is, without doubt, fays Dr. Lewis, highly emollient; but does not appear to have any other quality by which it can act in external applications; it has nothing of the acrimony or pungency which prevail in all the other known diftilled vegetable oils; though in fmell it is not a little difagreeable and empyreumatic; a circumftance which occafions it to be at prefent more rarely ufed than formerly. As the wax fwells up greatly in the diftillation, it is convenient to divide it, by melting it with twice its weight of fand; or putting the fand above it in the retort, that it may mingle with the wax when brought into fufion. The oil, which is preceded by a fmall quantity of acid liquor, congeals in the neck of the retort, from whence it may be melted down, by applying a live coal, and made fluid by rediftilling it two or three times without addition. The fæces remaining, after expreffing the wax, have been

ufed both by furgeons and farriers, with fuccefs, againft ftrains.

The officinal preparations are as follow: *cera flava purificata* of Dub. Ph.; *oxidum antimonii vitrificatum cera* of Edinb.; *emplaftrum ceræ* of Lond. and Edinb.; *emplaftrum cumini* of Lond.; *empl. picis compofitum* of Lond.; *empl. oxidi ferri rubri* of Edinb.; *empl. affafœtidæ* of Edinb.; *empl. gummofum* of Edinb.; *empl. meloes veficatorii* of Edinb. and Lond.; *empl. galbani* of Dub.; *empl. aromaticum* of Dub.; *ceratum* of Lond. and Dub.; *ceratum calamine* of Lond. and Dub.; *ceratum refinæ* of Lond. Edinb. and Dub.; *ceratum fabinæ* of Lond. and Dub.; *ceratum faponis* of Lond.; *unguentum picis aridæ* of Lond. and Edinb.; *ung. infufi meloes veficatorii* of Edinb.; and *ung. cantharidis* of Dub. Ph. For the firft, fee *white-wax* below. The fecond, or vitrified oxyd of antimony with wax, formerly waxed glafs of antimony, is formed by melting one part of yellow wax in an iron veffel, and throwing into it eight parts of oxyd of antimony vitrified with fulphur, reduced to powder, and roafting the mixture with a gentle fire for a quarter of an hour, ftirring it affiduoufly with a fpatula; then pouring out the latter, and when cold rubbing it into a powder. This preparation is diaphoretic and cathartic, occafionally exciting naufea and vomiting. It was formerly thought to poffefs efficacy in diarrhœa and dyfentery; but is now fcarcely ever prefcribed. The dofe may be from gr. ij. to gr. xv. given twice or three times a day. For the *empl. ceræ*, fee *Wax* PLASTER. For the 4th, fee EMPLASTRUM *é Cymino*. For the 5th, fee *Compound Pitch* PLASTER. For the 6th, fee PLASTER *of red Oxyd of Iron*. For the 7th, fee *Affa Fœtida* PLASTER. For the 8th, fee *Gum* PLASTER. For the 9th, 10th, and 11th, fee PLASTER. For the others, comprehending *cerates* and *ointments*. See UNGUENTUM.

The *bleached* or *white wax* is generally melted and caft, in the manner already ftated, into thin difcs, about 5 inches in diameter, in which form it is found in the fhops. For medical purpofes, it is regarded as a demulcent; and has been fometimes adminiftered in obftinate cafes of diarrhœa and dyfentery, with the view of fheathing the bowels; which effect is better produced by fimple mucilages and folutions. It is generally exhibited diffufed in mucilaginous fluids by means of foap, in the proportion of ⅓d part of the wax, with which it is firft melted, and then rubbed in a mortar, with the fluid gradually added; but a preferable method is faid to be that of Poerner, which is firft to melt the wax with olive oil, and then mix the oily compound while hot with the mucilaginous fluid, by triturating with the yolk of an egg. The dofe is a cupfull of the emulfion, containing about ℈j of wax, given every four or five hours. This wax, as well as the yellow fort, is much ufed in the compofition of plafters and ointments. The officinal preparations are *ceratum cetacei* of Lond. Edinb. and Dub. pharmacopeias; *unguentum cetacei* of Lond. and Dub.; *ung. hydrargyri nitrico-oxydi* of Lond.; *linimentum fimplex* of Edinb.; and *ung. fimplex* of Edinb. See CERATUM, LINIMENT, and UNGUENT. Lewis's Mat. Med.

Yellow wax is made foft with turpentine, yet retains its natural colour. Red wax is only the white melted with turpentine, and reddened with vermilion or alkanet. Verdigrife makes it green; and burnt paper, or lamp-black, black. Some travellers tell us of a natural black wax; affuring us there are bees, both in the Eaft and Weft Indies, that make an excellent honey, included in black cells. Of this wax, they fay, it is, that the Indians make thofe little vafes, in which they gather their balfam of Tolu.

WAX is alfo produced by the fecretion of many plants, and forms the filvery powder or bloom, which covers their leaves and fruit. It is found very abundantly combined with refin, covering the trunk of the wax-palm (*Ceroxylon*) of South America, found in the Quinoliu mountains, 180 feet high, with leaves 20 feet long, the trunk of which is covered with the waxy fecretion about two inches thick, and confifting of two-thirds of refin and one of wax; and very pure, encrufting the feeds of the *Myrica cerifera*, or wax-tree of Louifiana, and other parts of North America. The *Pe-la* of the Chinefe is an animal wax, and the white lac of India appears to be a variety of wax; fo that wax may be regarded, in the extended meaning of the term, both as an animal and a vegetable product. The croton febiferum, the tomex febifera, the poplar, the alder, the pine, as well as the Myrica, afford a concrete inflammable matter by decoction, that more or lefs refembles tallow or wax, that is, a fixed oil faturated with oxygen. But the Myrica cerifera fupplies it in the greateft abundance. The grains of this tree, and the fhining wax obtained by boiling them in water, have been long ago, *viz.* in 1722 and 1725, noticed in the Hiftory of the Academy of Sciences. The wax, it was obferved, is drier and more friable than our's; and it was found, that the liquor in which the grain had been boiled, and from which the wax was procured, afforded, on evaporation, a kind of extract that checked the moft obftinate dyfenteries; and the inhabitants of Louifiana are faid to have made candles of the wax. Several authors have mentioned different fpecies of thefe trees; but the wax they afford has more lately been the fubject of experimental inveftigation, particularly by M. Cadet and Dr. Boftock. The moft fertile of thefe fhrubs afford near feven pounds of berries, the gathering of which employ feveral families. Thefe berries are thrown into a kettle, and covered with water. Whilft the water is boiling, the grains are ftirred about againft the fides of the veffel, fo that the wax may more eafily come off. In a little time it floats on the water like fat, and being collected, is ftrained through a coarfe cloth, to free it from any impurities. This operation is repeated with frefh berries; and when a confiderable quantity of wax has been obtained, it is laid upon a cloth to drain off the water; and it is then dried and melted a fecond time; and when thus purified, formed into maffes. Four pounds of berries afford about one of wax: that which is firft obtained is generally yellow; but in the latter boilings it affumes a green colour, from the pellicle with which the kernel of the berry is covered. M. Cadet made a variety of experiments on thefe berries, and found that the powder which was obtained from them afforded an aftringent folution by alcohol, and that it contained gallic acid, but no tannin; and to this acid he attributes their effect in dyfenteries. The wax, obtained either by the decoction of the grains, or the folution of the powder when precipitated from alcohol by water, when melted, is always of a greenifh-yellow; of a firmer confiftence than bees'-wax, dry, and fufficiently friable to be pulverized; and evidently more oxygenated than the wax prepared by bees. Candles made of this wax yielded a white flame, a good light, without fmoke, and without guttering; and when quite frefh, they emit a balfamic odour, confidered in Louifiana as very falubrious to perfons in bad health. Diftilled in a retort, this wax, for the moft part, paffes over in the form of butter. This portion is much whiter, and has no more confiftence than tallow. Another portion that was decompofed afforded a little water, with fome empyreumatic oil and febacic acid. Much carbonated hydrogen gas and carbonic acid gas were difengaged; and there remained in the retort a black and coaly bitumen. Ether was found to diffolve

this wax better than alcohol. Oxygenated muriatic acid rendered this, as well as bees'-wax, perfectly white; but the vegetable wax was bleached with the greateſt difficulty. The ſolution in ammonia is of a brown colour, and a portion of the wax is rendered ſoapy; and it forms ſoap with fixed alkali. When the ſoap of Myrica is decompoſed, a very white wax is obtained, but in a ſtate unfit for our uſes. Litharge diſſolves very well in this melted wax, and forms a hard plaſter, the conſiſtence of which may be diminiſhed at pleaſure by the addition of a little oil. For bleaching this wax, M. Cadet obſerves, that two re-agents preſent themſelves to manufacturers, the ſulphuric acid and the oxygenated muriatic acid. He propoſes the following method as the moſt ſpeedy in its effect:—Let the wax be reduced to a very divided ſtate, and ſtratified in a caſk with ſuperoxygenated muriate of lime, and let them remain for ſome time in contact without water. Let the ſalt be afterwards decompoſed with water, acidulated by the ſulphuric acid; taking care to pour the water a little at a time at different intervals, until there ſhall be no longer any perceptible diſengagement of muriatic gas; at which period a large quantity of water is to be added, and the mixture agitated with a ſtaff. The inſoluble ſulphate of lime falls down by repoſe, while the bleached wax riſes and ſwims at the ſurface. This is to be waſhed and melted on the water bath. Our author cloſes his memoir with recommending the culture of the plant that yields this wax, and with a brief detail of methods for effecting this purpoſe. Dr. Boſtock has alſo proſecuted an inquiry into the nature and uſes of myrtle wax. He finds that in its more important properties it reſembles bees'-wax, but that in ſome reſpects they differ from one another. The myrtle wax is moderately hard and conſiſtent, poſſeſſing in part the tenacity of bees'-wax, without its unctuoſity, and alſo, in ſome degree, the brittleneſs of reſin. The prevalent colour is pale green, tending in moſt of the pieces to a dirty grey; in others it is lighter, more tranſparent, and of a yellowiſh tinge. Its ſpecific gravity is about 1.0150, water being 1.000, ſo that it ſinks in it, and the white bees'-wax being .9600. Water has no action upon it, either when cold or at the boiling heat. Alcohol, when cold, does not affect it; but 100 parts, by weight, of this fluid, when boiling, diſſolve about five parts of the wax. Nearly four-fifths are depoſited by the cooling of the alcohol; one-fifth remains ſuſpended, but in the courſe of a few days is ſlowly depoſited, or may be precipitated by the addition of water. Sulphuric ether, when at the common temperature of the atmoſphere, diſſolves only a ſmall quantity of this wax, but acts upon it rapidly when boiling. It takes up ſomewhat more than one-fourth of its own weight. As the ether cools, it is moſtly ſeparated, and the ſmall reſidue may be precipitated by water. After ſolution, the wax is nearly colourleſs, and the fluid aſſumes a beautiful green hue. The depoſit by evaporation ſomewhat reſembles ſpermaceti. Rectified oil of turpentine, at the temperature of the atmoſphere, ſoftens the wax, but does not diſſolve it: aided by a moderate heat, 100 grains of the turpentine diſſolves ſix grains of the wax. The turpentine acquires a light green tinge, part of the wax is ſeparated as the fluid cools, and part remains permanently diſſolved in it. Pure potaſh renders it colourleſs by boiling, and forms a ſoap with a ſmall part, which being decompoſed by acid, affords the wax nearly unchanged. Pure ammonia acts nearly as potaſh, but more feebly. The three principal mineral acids act upon the myrtle wax, but with no great force. The ſulphuric acid, with a moderate heat, diſſolves about one-twelfth of its weight, and converts it into a thick, dark-brown maſs, which on cooling becomes nearly concrete, but without any ſeparation of the wax. The nitric and muriatic acids, even when heated, ſeem to poſſeſs little attraction for the wax. From ſuch experiments, Dr. Boſtock aſſigns to myrtle wax, with a conſiderable degree of probability, the place which it ſhould occupy among chemical ſubſtances. Its inflammability, fuſibility, inſolubility in water, and the action which takes place between it and the alkalies, indicate its affinity to the fixed oils; while its texture and conſiſtence, and more particularly its habitudes with alcohol and ether, manifeſt a reſemblance to the reſins. Upon the whole, we may conſider the myrtle wax as a fixed vegetable oil, rendered concrete by the addition of a quantity of oxygen; and ſeeming to hold the ſame relation to the fixed, which reſins do to the eſſential oils of vegetables. Dr. Boſtock has inſtituted a compariſon between myrtle wax and other ſubſtances which it reſembles, ſuch as bees'-wax, ſpermaceti, adipocire, and the cryſtalline matter of biliary calculi; and, upon the whole, deduces this concluſion, that though theſe five ſubſtances poſſeſs certain properties in common, and have a degree of ſimilarity in their external appearance, yet that they differ materially in their chemical nature. There is indeed, he ſays, reaſon to conjecture, that they are all compoſed of the ſame elements, combined together in different proportions, and with different degrees of attraction. Nicholſon's Journal, vol. iv. 8vo.

WAX, *Chafe.* See CHAFE.

WAX, *Crude* or *Rough*, called by the French *cire brute*, in *Natural Hiſtory*, a name given to a ſubſtance called by the ancients *erithace*, *ſandarac*, and *ambroſia*.

We ſeem to have no name for it in Engliſh, but may call it after the name of the French, *rough wax*.

The Dutch call it the food of the bees, and that, perhaps, very properly, there appearing many reaſons to think that the bees eat it.

This is the yellow ſubſtance found on the hinder legs of bees in ſmall lumps, of which, as Reaumur and ſome others erroneouſly thought, wax is made by this inſect. See PAIN *d'Abeilles*.

WAX, *Myrtle.* See MYRICA, and WAX, *ſupra*.

WAX, *Virgin*, *Propolis*, is a ſort of reddiſh wax, uſed by the bees to ſtop up the clefts or holes of the hive. It is applied juſt as taken out of the hive, without any art, or preparation of boiling, &c. It is the moſt tenacious of any, and is held good for the nerves. See PROPOLIS.

WAX, *Sealing*, or *Spaniſh Wax*, is a compoſition of gum lacca, melted and prepared with reſins, and coloured with ſome ſuitable pigment.

There are two kinds of ſealing-wax in uſe: the one hard, intended for ſealing letters, and other ſuch purpoſes, where only a thin body can be allowed; the other ſoft, deſigned for receiving the impreſſions of ſeals of office to charters, patents, and ſuch written inſtruments.

The beſt hard red ſealing-wax is made by mixing two parts of ſhell-lac, well powdered, and reſin and vermilion, powdered, of each one part, and melting this combined powder over a gentle fire; and when the ingredients ſeem thoroughly incorporated, working the wax into ſticks. Seed-lac may be ſubſtituted for the ſhell-lac; and inſtead of reſin, boiled Venice turpentine may be uſed. A coarſer, hard, red ſealing-wax may be made, by mixing two parts of reſin, and of ſhell-lac, vermilion and red-lead, mixed in the proportion of one part of the vermilion to two of the red-lead, of each one part; and proceeding, as in the former preparation. For a cheaper kind, the vermilion may be omitted, and the ſhell-lac alſo, for very coarſe uſes. The hard black ſealing-wax may be prepared in the ſame manner;

ufing for the beft fort, inftead of the vermilion, the beft ivory black; and for the coarfer fort, inftead of the vermilion and red-lead, the common ivory black. For hard green fealing-wax, inftead of vermilion, ufe powdered verdigrife; and for a bright colour, diftilled, or cryftals of verdigrife. For hard blue fealing-wax, inftead of the vermilion, fubftitute well powdered fmalt, or for a light blue, verditer; or a mixture of both. For yellow hard fealing-wax, fubftitute mafticot, or, for a bright colour, turbith mineral, inftead of the vermilion. The hard purple wax is made like the red; changing half the quantity of the vermilion for an equal, or greater proportion of fmalt, as the purple is defired to be more blue or more red.

For uncoloured foft fealing-wax, take of bees'-wax, one pound; of turpentine, three ounces; and of olive oil, one ounce; place them in a proper veffel over the fire, and let them boil for fome time; and the wax will be then fit to be formed into rolls or cakes for ufe. For red, black, green, blue, yellow, and purple foft fealing-wax, add to the preceding compofition, while boiling, an ounce or more of any ingredients directed above for colouring the hard fealing-wax, and ftir the mafs, till the colouring ingredient be incorporated with the wax.

The hard fealing-wax is formed into fticks, by rolling the mafs on a copper-plate, or ftone, with a rolling-board, lined with copper, or block-tin, into rolls of any required fize. In order to give them the fire-polifh, or glofs, a furnace or ftove, like a pail, with bars at the bottom for fupporting the charcoal, and notches at the top of the fides for putting the fticks of wax over the fire, is ufually provided. By means of this ftove the fticks of wax may be conveniently expofed to the fire, and turned about, till the wax is fo melted on the furface as to become fmooth and fhining. Hard fealing-wax may be formed into balls, by putting a proper quantity on the plate or ftone, and having fafhioned it into a round form, rolling it with the board till it be fmooth.

The foft wax is eafily formed into rolls or cakes, by pouring the melted mafs of the ingredients, as foon as they are duly prepared, into cold water, and working it with the hands into any defired figure. Some perfume both thefe kinds of wax, by ufing, for a pound of the wax, half an ounce of benjamin, one fcruple of oil of Rhodium, ten grains of mufk, and of civet and ambergrife, each five grains; rubbing the oil with the other ingredients powdered; and when the wax is ready to be wrought into fticks, fprinkling in and well ftirring the mixture; or by ufing one ounce of benjamin, one fcruple and a half of oil of Rhodium, and five grains of ambergrife, in the fame manner. Lewis's Com. of Arts, p. 370. Handmaid to the Arts, vol. ii. p. 34, &c.

WAX-*Candles*. See CANDLE.

Weaving

WEAVING, in *Manufactures*, is the art of combining and uniting threads together, to form cloth. Stocking-knitting or weaving is a diſtinct art from cloth-weaving, the manner of combining the thread, being eſſentially different in the two. In the ſtocking fabric, the whole piece conſiſts of one continuous thread, which is formed into a ſeries of loops in ſucceſſive rows; and the loops of each row are drawn through the loops of a former row. See STOCKING-*Frame*.

Woven cloth is always compoſed of two diſtinct ſyſtems of threads, called the warp and the weft: theſe traverſe the piece of cloth in oppoſite directions, and are uſually at right angles to each other. Thoſe threads, (or, as the weavers call them, yarns,) which run in the direction of the length of the web or piece of cloth, are called the warp, and they extend entirely from one end of the piece to the other. The croſs thread, or yarn, runs acroſs the cloth, and is called the woof or weft. This is in fact one continued thread through the whole piece of cloth, being woven alternately over and under each yarn of the warp, which it croſſes, until it arrives at the outſide one. It then paſſes round that yarn, and returns back over and under each thread, as before; but in ſuch a manner, that it now goes over thoſe yarns which it paſſed under before, and *vice verſâ;* thus firmly knitting or weaving the warp together. The outſide yarn of the warp, round which the woof is doubled, is called the ſelvage, and cannot be unravelled without breaking the weft. The ſtrength of the cloth, in the direction of the length, muſt depend on the threads of the warp; but its ſtrength in the oppoſite direction will depend upon the weft; and the ſtrength of theſe two threads ſhould be always properly proportioned to each other.

The combined arts of ſpinning and weaving are among the firſt eſſentials of civilized ſociety, and we find both to be of very ancient origin. The fabulous ſtory of Penelope's web, and, ſtill more, the frequent alluſions to this art in the ſacred writings, tend to ſhew, that the fabrication of cloth from threads, hair, &c. is a very ancient invention. It has, however, like other uſeful arts, undergone a vaſt ſucceſſion of improvements, both as to the preparation of the materials of which cloth is made, and the apparatus neceſſary in its conſtruction, as well as in the particular modes of operation by the artiſt. Weaving, when reduced to its original principle, is nothing more than the interlacing of the weft or croſs threads into the parallel threads of the warp, ſo as to tie them together, and form a web or piece of cloth. This art is doubtleſs more ancient than that of ſpinning, and the firſt cloth was what we now call matting, *i. e.* made by weaving together the ſhreds of the bark, or fibrous parts of plants, or the ſtalks, ſuch as ruſhes and ſtraws.

This is ſtill the ſubſtitute for cloth amongſt moſt rude and ſavage nations. When they have advanced a ſtep farther in civilization than the ſtate of hunters, the ſkins of animals become ſcarce, and they require ſome more artificial ſubſtance for clothing, and which they can procure in greater quantities. Nevertheleſs, ſome people are ſtill ignorant of the art of weaving; for the cloth made in the iſlands of the South ſea appears to be made by cementing or glueing the ſhreds together, rather than by weaving. From the deſcription given by captain Cook, and other circumnavigators, and from the ſpecimens which have been brought to Europe, their cloth, or rather matting, is in general produced by coheſion of the parts, rather than texture. This aſſimilates it more to the ideas which we attach to paper, or paſteboard, than to thoſe which we form of cloth.

When it was diſcovered that the delicate and ſhort fibres, which animals and vegetables afford, could be ſo firmly united together by twiſting, as to form threads of any required length and ſtrength, the weaving art was placed on a permanent foundation. By the proceſs of ſpinning, which was very ſimple in the origin, the weaver is furniſhed with threads far ſuperior to any natural vegetable fibres in lightneſs, ſtrength, and flexibility; and he has only to combine them together in the moſt advantageous manner.

The art of weaving cloth has been ſo extenſively applied

in almoſt every civilized country, and the knowledge of its various branches has been derived from ſuch a variety of ſources, that no one perſon can ever be practically employed in all its branches; and though every part bears a ſtrong analogy to the reſt, yet a minute knowledge of each of theſe parts can only be acquired by experience and reflection. We will endeavour to give the reader as comprehenſive an idea of the hiſtory and progreſs of this ancient and invaluable art as the nature of the thing, and the limits to which we are neceſſarily confined, will permit.

The hiſtory of this art is very little known, and its great antiquity neceſſarily involves the earlier eras of it in the moſt perfect obſcurity.

The art of making linen, which was probably the firſt ſpecies of cloth invented, was communicated by the Egyptians, the inhabitants of Paleſtine, and other eaſtern nations, to the Europeans. By ſlow degrees it found its way into Italy; and it afterwards prevailed in Spain, Gaul, Germany, and Britain. The Belgæ manufactured linen on the continent; and when they afterwards ſettled in this iſland, it is probable they continued the practice, and taught it to the people among whom they reſided.

When it is conſidered that the wants of mankind are nearly the ſame in all countries, it is not improbable that the ſame arts, however varied in their operations, may have been ſeparately invented in different countries. It is not, however, certain that the art of making cloth is one which the Britons invented for themſelves.

It is moſt probable that the Gauls learned it from the Greeks, and communicated the knowledge of it to the people of Britain. It is very certain that the inhabitants of the ſouthern parts of Britain were well acquainted with the arts of dreſſing, ſpinning, and weaving, both flax and wool, when they were invaded by the Romans. Nevertheleſs, we have the authority of Julius Cæſar, that when he invaded Britain, the art of weaving was totally unknown to the Britons.

Whatever knowledge the Britons might poſſeſs of the clothing arts, prior to the invaſion, it is very certain that theſe arts were much improved amongſt them after that event. It appears from the Notitia Imperii, that there was an imperial manufactory of woollen and linen cloth, for the uſe of the Roman army then in Britain, eſtabliſhed at Venta Belgarum, now called Wincheſter.

Many public acts relative to the woollen manufacture, in the earlier period of Engliſh hiſtory, evidently prove that the greater part of our wool was, for a very long ſeries of years, exported in a raw ſtate, and manufactured upon the continent.

In biſhop Aldhelm's book concerning "Virginity," written about A.D. 680, it is remarked, "that chaſtity alone forms not a perfect character, but requires to be accompanied and beautified by other virtues." This obſervation is illuſtrated by the following ſimile, borrowed from the art of figure-weaving: "It is not a web of one uniform colour and texture, without any variety of figures, that pleaſeth the eye, and appeareth beautiful; but one that is woven by ſhuttles, filled with threads of purple, and many other colours, flying from ſide to ſide, and forming a variety of figures and images, in different compartments, with admirable art."

Perhaps the moſt curious ſpecimen of this ancient figure-weaving and embroidery, now to be found, is that preſerved in the cathedral of Bayeaux. It is a piece of linen, about 19 inches in breadth, and 67 yards in length, and contains the hiſtory of the Conqueſt of England by William of Normandy; beginning with Harold's embaſſy, A.D. 1065, and ending with his death at the battle of Haſtings, A.D. 1066. This curious work is ſuppoſed to have been executed by Matilda, wife to William, duke of Normandy, afterwards king of England, and the ladies of her court. Although it is certain that the art of figure-weaving was then known in Britain, it muſt be owned, that the piece of tapeſtry juſt mentioned owes moſt of its beauty to the exquiſite needle-work with which it is adorned.

The ſilk manufacture was firſt practiſed in China, and the cotton in India. Both the woollen and linen were borrowed by the Engliſh from the continent of Europe; and for many ages, all the improvements in them in this country were firſt introduced into this country by foreign artificers, who ſettled amongſt us.

About the cloſe of the eleventh century, the clothing arts had acquired a conſiderable degree of improvement in this iſland. About that time, the weavers in all the great towns were formed into guilds or corporations, and had various privileges beſtowed upon them by royal charters.

In the reign of Richard I., the woollen manufacture became the ſubject of legiſlation; and a law was made, A.D. 1197, for regulating the fabrication and ſale of cloth.

The number of weavers, however, was comparatively ſmall, until the policy of the wiſe and liberal Edward III. encouraged the art, by the moſt advantageous offers of reward and encouragement to foreign cloth-workers and weavers, who would come and ſettle in England. In the year 1331, two weavers came from Brabant, and ſettled at York.

The ſuperior ſkill and dexterity of theſe men, who communicated their knowledge to others, ſoon manifeſted itſelf in the improvement and ſpread of the art of weaving in this iſland.

Many Flemiſh weavers were driven from their native country, by the cruel perſecutions of the duke d'Alva, in the year 1567. They ſettled in different parts of England, and introduced or promoted the manufacture of baizes, ſerges, crapes, and other woollen ſtuffs.

About the year 1686, nearly 50,000 manufacturers, of various deſcriptions, took refuge in Britain, in conſequence of the revocation of the edict of Nantz, and other acts of religious perſecution committed by Louis XIV. Theſe improvements chiefly related to ſilk-weaving.

The arts of ſpinning, throwing, and weaving ſilk, were brought into England about the middle of the 15th century, and were practiſed by a company of women in London, called ſilk-women. About A. D. 1480, men began to engage in the ſilk manufacture, and the art of ſilk-weaving in England ſoon arrived at very great perfection. See Silk.

The civil diſſentions which followed this period, retarded the progreſs of theſe arts; but afterwards, when the nation was at reſt, the arts of peace, and among others that of weaving, made rapid advances in almoſt every part of the kingdom.

In the latter part of the laſt century, the invaluable inventions of ſir Richard Arkwright, introduced the very extenſive manufacture of cotton, and added a lucrative and elegant branch of traffic to the commerce of Britain. The light and fanciful department of the cotton manufacture has become, in ſome meaſure, the ſtaple manufacture of Scotland, whilſt the more ſubſtantial and durable cotton fabrics have given to England a manufacture inferior, in importance and extent, only to the woollen trade.

At the preſent day, our ſuperiority in point of quality

is univerfally acknowledged in the cotton manufacture; but in thofe of filk, linen, and woollen, it is ftill difputed by other countries.

Loom.—Weaving is performed by the aid of a machine called a loom. The common loom for plain cloth is a very fimple machine; but fome of the varieties which are ufed for weaving ornamental and figured cloth are very curious: ftill there are parts common to all. The principal of thefe are as follows.

1. The yarn-beam, which is a round wooden roller, on which is wound or rolled the warp, or yarns that are to form the length of the piece of cloth. 2. The cloth-beam is a fimilar roller, on which the cloth is rolled up when woven. The yarns of the warp are extended in parallel lines, between the yarn-roll and the cloth-roll, fo as to form a horizontal plane, or fheet, and are combined together by the crofs-threads, or weft. 3. The fhuttle, which has a hollow to contain a bobbin or pirn of the weft. 4. The heddles, which are threads with loops or eyes, through which the yarns of the warp pafs: the heddles are connected with the treadles, upon which the weaver places his feet, to draw down one fet of heddles and raife up another, fo as to open and feparate the warp into two divifions, and allow a paffage, called the fhed, for the fhuttle between them. 5. The reed, which is a frame containing a row of parallel fhreds of reeds or cane, and the yarns of the warp pafs between them, as it were between the teeth of a comb. 6. The reed is fixed in a frame, called the lay or lathe, which fwings upon centres of motion. The ufe of the reed and lay is to comb or pufh the threads of the weft clofe to each other, and make the cloth clofe and denfe.

The operation of weaving or working the loom for plain cloth confifts of three very fimple movements, *viz.* 1. Openning the fhed in the warp alternately, by preffing the two treadles with his feet in oppofite directions. 2. Driving or throwing the fhuttle through the fhed when opened. This is performed by the right-hand, when the fly-fhuttle is ufed, and by the right and left alternately, in the common operation, wherein the fhuttle is thrown from one hand and caught in the other. 3. Pulling forward the lay or batten to ftrike home the woof, and again pufhing it back nearly to the heddles. This is done by the left-hand with the fly-fhuttle, or by each hand fucceffively in the old way.

There are feveral different ways of fetting up a loom for weaving plain cloth; but the principal parts are always made the fame. We fhall firft defcribe that which is ufed for weaving plain filks: it is fhewn in perfpective in *Plate* II. *Weaving.* In this A is the yarn-roll or beam, on which the thread to form the warp is regularly wound; B, the cloth-beam, or breaft-roll, on which the finifhed cloth is wound up; D E, the treadles, on which the weaver preffes his feet; *dd*, *ee*, are the heddles, or harnefs. Thefe are each compofed of two fmall rods *dd* and *ee*, connected together by feveral threads, forming a fyftem of threads, which is called a heddle; *ee* is another heddle, behind the former. In the middle of each thread of the heddle is a loop, through which a yarn of the warp is paffed, every other yarn going through the loops of the heddle *ee*, and the intermediate yarns paffing between the threads of that heddle, and afterwards through the eyes or loops of the other heddle *dd*.

The two heddles, *dd* and *ee*, are connected together by two fmall cords going over pulleys, fufpended from the top of the loom, fo that when one heddle is drawn down, the other will be raifed up. The heddles receive their motion from the levers or treadles D E, moved by the weaver's feet. The yarns of the warp being paffed alternately through the loops of the two heddles, by preffing down one treadle, as E, all the yarns belonging to the heddle *ee* are drawn down; and by means of the cords and pulleys, the other heddle *dd*, with all the yarns belonging to it, are raifed up; leaving a fpace, called the fhed, of about two inches between the yarns, for the paffage of the fhuttle.

F, G G, H, (*fig.* 2.) is a frame, called the batten or lay, fufpended by the bar F, from the upper rails of the loom, fo that it can fwing backwards and forwards, as on a centre of motion; the bottom bar H is much broader than the rails G G, and projects before the plane about an inch and a half, forming a fhelf, called the fhuttle-race. The ends of the fhuttle-race H have boards nailed on each fide, to form two fhort troughs or boxes I I, in which pieces of wood or thick leather *k k*, called peckers or drivers, traverfe. The peckers are guided by two fmall wires, fixed at one end to the uprights G G, and at the other to the end-pieces of the troughs I I. Each pecker has a ftring faftened to it, tied to the handle *y*, which the weaver holds in his right-hand when at work, and with which he pulls, or rather fnatches, each pecker either to the right or left alternately.

R is the reed: it is a fmall frame, fixed upon a fhuttle-race H, containing a number of fmall pieces of fplit reeds or canes; or elfe of pieces of flat wire, of fteel or brafs; but the cane is moft common, although the frame is called the reed. When *fig.* 2. is in its place in the loom, the yarns of the warp pafs between the canes or dents of the reed. In *fig.* 2. the reed is reprefented without the top or piece which covers it, and which is called the lay-cap. It is a rail of wood with a longitudinal groove along its lowermoft fide, for the purpofe of fuftaining the upper edge of the reed. The lay-cap is that part of the machine on the middle of which the weaver lays hold with his left-hand when in the act of weaving.

The fhuttle (fee *Plate* I.) is a fmall piece of wood pointed at each end, from three to fix inches long. It has an oblong mortife in it, containing a fmall bobbin or pirn, on which is wound the yarn which is to form the weft; and the end of this yarn runs through a fmall hole in the fhuttle, called the eye. The fhuttle has two little wheels on the under fide, by which it runs eafily upon the fhuttle-race H.

Operation.—The weaver fits on the feat M, (*fig.* 1.) which hangs by pivots at its ends, that it may adapt itfelf to the eafe of the weaver when he fits upon it. It is lifted out when the weaver gets into the loom, and he puts it in again after him. He leans lightly againft the cloth-roll B, and places his feet upon the treadles D E. In his right-hand he holds the handle *y* (*fig.* 2.), and by his left he lays hold of the rail, called the lay-cap, which croffes the batten or lay G G, and ferves to fupport the upper edge of the reed R. He commences the operations by preffing down one of the treadles with his foot: this depreffes one-half of the yarns of the warp, and raifes the other, as before-defcribed. The fhuttle is previoufly placed in one of the troughs I, againft the pecker K, belonging to that trough. By the handle of the pecker, with a fudden jerk, he drives the pecker againft the fhuttle, fo as to throw it acrofs the warp upon the fhuttle-race, into the other trough I, leaving the yarn of the weft, which was wound on the bobbin after it, in the fpace between the divided yarns. With his left-hand he pulls the lay towards him; and, by means of the reed, the yarn of the weft, which before was lying loofe between the warp, is driven up towards

the cloth-roll: the weaver now presses down his other foot, which reverses the operation, pulling down the heddle which was up before, and raising that which before was depressed. By the other pecker he then throws the shuttle back again, leaving the woof after it between the yarns of the warp; and, by drawing up the batten, beats it close up to the thread before thrown.

In this manner the operation is continued until a few inches are woven; it is then wound upon the cloth-roll, by putting a short lever into a hole made in the roll, and turning it round, a click acting in the teeth of a serrated wheel, prevents the return of the roll. At each end of the yarn-roll A, (*fig.* 1.) a cord is tied to the frame of the loom; the other ends of the cords have weights hanging to them. The rope causes a friction, which prevents the roll from turning (unless the yarn is drawn by the cloth-beam), and always preserves a proper degree of tension in the yarn.

T T (*fig.* 1.) are two smooth sticks (cotton-weavers have usually three) put between the yarns, to preserve the lease, and keep the threads or yarns from entangling.

In cotton-weaving these sticks or rods are kept at an uniform distance from the heddles, either by tying them together, or by a small cord with a hook at one end, which lays hold of the front rod, and a weight at the other, which hang over the yarn-beam.

The cloth is kept extended during the operation of weaving, by means of two hard pieces of wood, called a templet, with small sharp points in their ends, which lay hold of the edges, or selvages, of the cloth.

These pieces are connected by a cord passing obliquely through holes, or notches, in each piece. By this cord they can be lengthened or shortened, according to the breadth of the web.

They are kept flat after the cloth is stretched by a small bar turning on a centre fixed in one of the pieces of wood. This stretcher is called the templet. Silk-weavers usually stretch their cloth by means of two small sharp-pointed hooks fastened to the ends of two strings, with little weights at the other ends; and the strings are made to pass over little pulleys in each side of the loom, at a suitable distance from the selvages of the cloth.

The perfection of the work depends very much upon the previous operations which the yarn must undergo. It is obvious that the yarns of the warp must be stretched with great parallelism and equality of tension, so that when the cloth is finished, every individual yarn may bear an equal share of any strain which tends to tear the cloth; hence great care must be taken to stretch the yarns of the warp to an equal length, and roll them with great regularity upon the yarn-roll. These operations are called warping and beaming. Previous to warping, the yarn must be prepared by sizing or starching, in order to cement all the loose fibres, and render the yarn smooth.

The spinners of yarn, whether they employ machinery or not, usually reel the yarn into skeins and hanks of a determinate length; and the weight of these hanks, or the number which will weigh one pound, is the denomination for the fineness of the yarn. (See *Manufacture of* COTTON.) In this state the yarn is bought by the weaver. The hanks of yarn are first boiled in water; if it is linen-yarn a little soap and potash are put into the water, and for cotton-yarn a small portion of flour is added, to render the thread firm. When the hanks are perfectly dry they are wound off upon bobbins, each thread having a separate bobbin, and a certain length is wound upon each. This winding is performed by a very simple hand-wheel to turn the bobbin rapidly round, the hanks of yarn being extended upon a reel, or over two small reels placed at a distance asunder, which are called wisks.

Warping.—The object of this operation is to stretch the whole number of parallel threads which are to form the warp of the cloth to an equal length. For this purpose as many of the above bobbins are taken as will furnish the quantity of threads which is required in the warp of the piece of cloth. The bobbins are usually one-fourth or one-sixth of the number of threads required, and are mounted on spindles in a frame, so that the thread can draw off freely from them. All these threads are drawn off at once, so as to combine them all into one clue, which will be ready for the warp. The ancient method was to draw out the warp at full length, and stretch it in a field; and this is still practised in India and China, but is so very uncertain in our climate that it is seldom used. The present mode of warping is either by the warping-frame or warping-mill.

The warping-frame is a large wooden frame, which is fixed up against a wall in a vertical position. The upright sides of the frame are pierced with holes to receive wooden pins, which project sufficiently to wind the clue of yarns for the warp round them.

The operator having the threads which are to compose the warp wound on the bobbins before-mentioned, places those bobbins in a frame; then tying the ends of all the threads together, and attaching them to one of the pins at one end of the frame, he gathered all the threads in his hand into one clue; and permitting them to slip through his fingers, he walked to the other end, where he passed the yarns over the pin fixed there, and then returned to the former end of the frame and passed the warp over another pin, then went back again, and so on till he formed the required length of the warp. This being done, he secured the end of the warp by crossing it round the pin, and then he worked back and returned over all the same space again, laying the threads over the same pins, so as to double the clue; and he repeated the doubling until the number of threads necessary for the breadth was made up. The number of doublings would be according to the number of bobbins and threads which he took in his hand at once.

This method is used very much in France, particularly at Lyons: it is also used in Devonshire. It is adapted to the weaving carried on in cottages, because the frame is fixed close to the wall, and takes little or no room; but the warping-mill or reel is very superior, and is adopted in all improved manufactures where the warping is a separate business, and is usually done at the mill where the yarn is spun.

The warping-mill is a large reel of a cylindrical form, or rather of a prismatic form, being made with twelve, eighteen, or more sides. The reel is usually about six feet diameter and seven feet high: it is turned round on a vertical axis by a band, passing from a grooved wheel which is turned by a winch, and is placed beneath the seat on which the warper sits. (See a figure of the warping-machine for silk *Plate Silk*, *fig.* 6.) The bobbins which contain the yarn are placed on a vertical rack suspended from the ceiling, and the threads from them are all collected together and passed between two small upright rollers in a clue, which is wound up by the reel when it is turned round. To guide the clue and distribute it equally on the length of the reel, the above rollers are fixed on a piece of wood, which slides perpendicularly on an upright bar fixed at one side of the reel. The sliding-piece is suspended by a small cord, wrapped round a part of the perpendicular axis that rises above the reel. The cord passes over a pulley at the top of the upright bar, and goes down to the sliding-piece which carries the two rollers. When the reel turns round, the guide-rollers are slowly

drawn up by the coiling of this cord round the axis; and the yarn is wound in a regular ſpiral about the reel, until the length which the warp requires is wound upon it. When the full length of the yarn is wound on the reel, the clue of thread is croſſed over pins projecting from the frame of the reel, and the mill is then turned the reverſe way, ſo that the ſlider and guide-rollers deſcend, and the yarn is laid downwards along the ſame ſpiral which it before aſcended, ſo as to double the clue of thread; and this doubling is repeated until the required number of threads is collected together in one clue upon the reel.

When the warp is thus completed, it is taken off the reel and wound upon a ſtick into a ball; the croſſings which diſtinguiſh the different returns or doublings of the ſimple clue being firſt properly ſecured, as a means of dividing the warp into as many equal portions as is neceſſary for the convenience of the weaver, in counting the threads in the ſucceeding operation of beaming.

There is likewiſe another kind of diviſion of the threads of the warp; this is called the leaſe, and ſerves to ſeparate all the threads which are to go through one of the heddles of the loom, from thoſe which are to go through the other heddle. To effect this ſeparation, the bobbins from which the threads are drawn are arranged in two rows, and a thread is alternately drawn from the upper row and from the lower row. Then at the beginning and end of every doubling of the warp, the threads of one row of bobbins are croſſed over the threads of the other row, and two pins are put into the croſſings to retain them. Theſe pins are put into holes made in pieces of board fixed to the warping-reel. One of theſe boards at the top of the reel is fixed faſt, but the other is moveable, and can be fixed at any part of the reel, according to the length of the warp.

In the moſt improved warping-machines, the ſeparation is made by an apparatus called in Scotland the heck. It conſiſts of a row of ſteel pins with eyes through one end of each for the threads to paſs through like large needles. Theſe are ſtuck into two pieces of wood, by which they are ſupported in a row near to the warping-reel. Every alternate pin in the row is faſtened in one piece of wood, and the intermediate pins are faſtened in the other piece, ſo that by lifting up one piece of wood the pins and threads belonging to it will be raiſed up, whilſt the intermediate pins and threads are held down. This occaſions the diviſion of the threads, and a pin is put in to keep them ſo divided. The other piece of wood is then lifted up, which occaſions all the threads to be croſſed; that is, every thread forms a croſs over that which is adjacent to it. A ſecond pin is then put in, and before the warp is taken off from the reel, this croſſing is ſecured by a ſtring.

Beaming.—When the weaver receives his warp in a large ball or bundle, he proceeds to roll it up regularly upon the yarn-roller of his loom: this is called beaming. For this purpoſe he employs an inſtrument called a ſeparator, or ravel, which conſiſts of a number of ſhreds of cane, faſtened together, and fixed to a rail of wood, like the teeth of a long comb; the threads are intended to be put into the ſpaces between theſe teeth, ſo as to ſtretch the warp to its proper breadth.

Ravels are ſomewhat like reeds, but much coarſer, and are alſo of different dimenſions. One proper for the purpoſe being found, one of the ſmall diviſions of the warp is placed in every interval between two of the teeth. The upper part of the ravel, called the cape, is then put on, to ſecure the threads from getting out between the teeth, and the operation of winding the warp upon the beam commences. In broad works, two perſons are employed to hold the ravel, which ſerves to guide the threads of the warp, and to ſpread them regularly upon the beam; one or two other perſons keep the threads at a proper degree of tenſion, and one more turns the beam upon its centre.

The knottings which ſecure the croſſings or doublings made in warping, are very uſeful to the weaver in beaming, to aſcertain the number of threads, and to diſtribute them with regularity. He cuts the knotting before he can put the warp in the ravel, but he ſtill keeps them diſtinct by a ſmall cord.

The French weavers uſe a ſmall reel, upon which they wind the warp from the ball, and then from this reel they draw off the warp through the ravel, by winding up the beam. The reel is loaded with a weight, to make a regular friction, and draw the warp with a regular tenſion.

Drawing.—The warp being regularly wound upon the beam, the weaver muſt paſs every yarn through its appropriate eye or loop in the heddles: this operation is called drawing. Two rods are firſt inſerted into the leaſe formed by the pins in the warping-mill, and the ends of theſe rods are tied together; the twine by which the leaſe was ſecured is then cut away, and the warp ſtretched to its proper breadth. The yarn-beam is ſuſpended by cords behind the heddles, ſomewhat higher, ſo that the warp hangs down perpendicularly. The weaver places himſelf in front of the heddles, and opens the eye of each heddle in ſucceſſion; and it is the buſineſs of another perſon, placed behind, to ſelect every thread in its order, and deliver it to be drawn through the open eyes of the heddles. The ſucceſſion in which the threads are to be delivered is eaſily aſcertained by the leaſe-rods, as every thread croſſes that next to it. The warp, after paſſing through the heddles, is drawn through the reed by an inſtrument called a ſley, or reed-hook, and two threads are taken through every interval in the reed.

The leaſe-rods being paſſed through the intervals which form the leaſe, every thread will be found to paſs over the firſt rod, and under the ſecond; the next thread paſſes under the firſt, and over the ſecond, and ſo on alternately. By this contrivance every thread is kept diſtinct from that on either ſide of it, and if broken, its true ſituation in the warp may be eaſily and quickly found. This is of ſuch importance, that too much care cannot be taken to preſerve the accuracy of the leaſe. There is likewiſe a third rod, which divides the warp into what is uſually called *ſplitfuls*, for two threads alternately paſs over and under it; and theſe two threads alſo paſs through the ſame interval betwixt the ſplits of the reed.

Theſe operations being finiſhed, the cords or mounting which move the heddles are applied; the reed is placed in the lay, or batten, and the warp is knotted together into ſmall portions, which are tied to a ſhaft, and connected by cords to the cloth-beam, and the yarns are ſtretched ready to begin the weaving.

Manner of Weaving.—The operations of weaving are ſimple, and ſoon learned, but require much practice to perform them with dexterity.

In preſſing down the treadles of a loom, moſt beginners are apt to apply the weight or force of the foot much too ſuddenly. The bad conſequences of this are particularly felt in weaving fine or weak cotton-yarn; for the body of the warp muſt ſuſtain a ſtreſs nearly equal to the force with which the weaver's foot is applied to the treadle. The art of ſpinning has not yet been brought to ſuch perfection as to make every thread capable of bearing its fair proportion of this ſtreſs. Beſides this, every individual thread is ſubjected to all the friction occaſioned by the heddles and ſplits of the reed, between which the threads paſs, and with

which they are generally in contraſt when riſing and ſinking. A ſudden preſſure of the foot on the treadle muſt cauſe a proportional increaſe of the ſtreſs upon the warp, and alſo of the friction. As it is impoſſible to make every thread equally ſtrong and equally tight, thoſe which are the weakeſt, or the tighteſt, muſt bear much more than their equal proportion of the ſtreſs, and are broken very frequently. Even with the greateſt attention, more time is loſt in tying and replacing them, than would have been ſufficient for weaving a very conſiderable quantity into cloth.

If the weaver, from inattention, continues the operation after one or more warp-threads are broken, the conſequence is ſtill worſe. The broken thread cannot retain its parallel ſituation to the reſt, but croſſing over or between thoſe neareſt to it, either breaks them alſo, or interrupts the paſſage of the ſhuttle: it frequently does both.

In every kind of weaving, and eſpecially in thin wiry fabrics, much of the beauty of the cloths depends upon the weft being well ſtretched. If the motion given to the ſhuttle be too rapid, it is very apt to recoil, and thus to ſlacken the thread. It has alſo a greater tendency, either to break the woof altogether, or to unwind it from the pirn or bobbin of the ſhuttle in doubles, which, if not picked out, would deſtroy the regularity of the fabric. The weft of muſlins and thin cotton goods is generally woven into the cloth in a wet ſtate.

This tends to lay the ends of the fibres of cotton ſmooth and parallel, and its effect is ſimilar to that of dreſſing of the warp.

The perſon who winds the weft upon the pirn ought to be very careful that it be well formed, ſo as to unwind freely. The beſt ſhape for thoſe uſed in the fly-ſhuttle is that of a cone; and the thread ought to traverſe freely round the cone, in the form of a ſpiral, or ſcrew, during the operation of winding.

The ſame wheel which is uſed for winding the warp upon the bobbins preparatory to warping, is alſo fit for winding the weft on the pirn. It only requires a ſpindle of a different ſhape, with a ſcrew at one end, upon which the pirn, or bobbin of the ſhuttle, can be fixed. The wheel is ſo conſtructed, that the ſpindles may be eaſily ſhifted, to adapt it for either purpoſe.

The reeds are formed of a number of ſhort pieces of reed or cane, or of braſs wire, faſtened parallel to each other between two ſticks, and cemented with pitch. This frame is encloſed between two pieces of the frame of the lay, one of which is made wide, to form the ſhuttle-race; the other piece, which is the lay-cap, extends acroſs the frame, but is fitted ſo that it can be eaſily removed to take away the reeds, and ſubſtitute a finer or coarſer ſort, as the nature of the goods to be woven require. The manufacture of reeds, both of cane and of ſteel, is a ſeparate trade. Theſe are fully deſcribed in Les Arts et Metiers, vols. 9 and 15.

To render the fabric of the cloth uniform in thickneſs, the lay or batten muſt be brought forward with the ſame force every time.

In weaving ſome kinds of ſoft or light goods, the reed is not fixed faſt to the lay-cap, but is held in its place by a long thin piece of wood, which is elaſtic, and yields or ſprings when the weft is beaten up. In ſome caſes the reed is ſuſtained by a double woollen cord, ſtretched acroſs the lay, juſt beneath the lay-cap, and twiſted; this bears the reed, and is very elaſtic, but can be rendered more ſtiff by twiſting the two cords tighter.

In the common operation of weaving, a regular force of the ſtroke for beating up the weft muſt be acquired by practice. It is, however, of conſequence to the weaver to mount or prepare his loom in ſuch a manner, that the range or ſwing of the lay may be in proportion to the thickneſs of his cloth. As the lay ſwings backwards and forwards, upon centres placed above, its motion is ſimilar to that of a pendulum. Now the greater the arc, or range through which the lay paſſes, the greater will be its effect in driving home the weft ſtrongly, and the thicker the fabric of cloth will be, as far as that depends upon the cloſeneſs of the weft. For this reaſon, in weaving coarſe and heavy goods, the heddles ought to be hung at a greater diſtance from the place where the weft is ſtruck up, and conſequently where the cloth begins to be formed, than would be proper in light work. The line of the laſt wrought ſhot of weft is called by the weavers the fell. The pivots upon which the lay vibrates ought, in general, to be ſo placed, that the reed will be exactly in the middle, between the fell and the heddles, when the lay hangs perpendicularly. As the fell is conſtantly varying in its ſituation during the operation, it will be proper to take its medium; that is, the place where the fell will be when half as much is woven as can be done without taking it up on the cloth-roll, and drawing freſh yarn from the yarn-roll.

The periods for taking up the cloth ought always to be ſhort in weaving light goods; for the leſs that the extremes of the fell vary from the medium, the more regular will be the arc or ſwing of the lay. Mr. James Hall had a patent, in 1803, for a method of perpetually winding up the cloth-beam, ſo as to take away the cloth as faſt as it was woven, or ſhoot by ſhoot. This was effected in a ſimple manner by a ratchet-wheel fixed on the end of the cloth-beam, and a proper catch to move it round one tooth at a time: the catch was actuated by the motion of the lay. A ſimilar method is uſed in ribband-weaving.

The variations in the ſtructure of looms from that which we have deſcribed, are not material. The framing is varied in almoſt every different kind of loom, and ought always to be ſuitable in ſtrength to the kind of cloth which is to be woven. The loom uſed for ſilk is very ſlight in all its parts; but for carpet and ſail-cloth it muſt be very ſtrong.

In looms for heavy goods, the cloth-beam is not placed at the breaſt of the weaver, as it is ſo large that it would impede his working; the cloth is therefore paſſed over a fixed bar in the place of the cloth-beam repreſented, and the beam is placed lower down, and near the weaver's feet, out of the way of his knees. The heddles are connected by levers, in ſome looms, inſtead of pulleys; but the effect is always the ſame; *viz.* to make one heddle aſcend when the other deſcends. For weaving fine goods, the heddles would be inconveniently cloſe together, if all the yarns went through two heddles; hence they uſe four heddles inſtead of two; but their action is juſt the ſame, becauſe they are connected together in pairs, and when one pair riſes the other pair ſinks. Many looms are ſtill made without the fly-ſhuttle; and in that caſe the ſhuttle is merely thrown from one hand to the other, and then thrown back again: this obliges the weaver to change his hands continually, and the operation is more complicated. For wide cloths, which are more than a man can reach acroſs, two perſons were always employed before the fly-ſhuttle was introduced, which is only within a few years; but by its aſſiſtance one perſon can weave the greateſt breadths. The fly-ſhuttle is the beſt for all kinds of work, and its conſtruction is ſo ſimple that no other ought to be uſed.

Treatment of different Kinds of Yarns.—The manner of weaving all kinds of plain cloth is much the ſame, whether it is wool, ſilk, flax, or cotton; except that the two latter

require what is called dreſſing. Silk and woollen warps require little preparation after being put into the loom, except to clear the yarn occaſionally with a comb, to remove knots or lumps which might catch in paſſing through the reed; the comb detects ſuch lumps, and they are removed with the aſſiſtance of a pair of ſciſſors. Flax and cotton, but particularly the latter, require the warp to be dreſſed with ſome glutinous matter, to cement the fibres, and lay them cloſe. This is applied in a fluid ſtate, and as the weaving does not proceed well after it is ſuffered to dry, the warp is dreſſed with a bruſh when in the loom, a ſmall quantity at a time, immediately before it is woven.

Dreſſing.—The uſe of dreſſing is to give to yarn ſufficient ſtrength or tenacity, to enable it to bear the operation of weaving into cloth. By laying ſmooth all the ends of the fibres of the raw materials, from which the yarn is ſpun, it tends both to diminiſh the friction during the proceſs, and to render the cloth ſmooth and gloſſy when finiſhed. The dreſſing in common uſe is ſimply a mucilage of vegetable matter boiled to a conſiſtency in water. Wheat-flour, boiled to a paſte like that uſed by book-binders, or ſometimes potatoes, are commonly employed. Theſe anſwer ſufficiently well in giving to the yarn both the ſmoothneſs and tenacity required; but the great objection to them is, that they are too eaſily affected by the action of the atmoſphere. When dreſſed yarn is allowed to ſtand expoſed to the air for any conſiderable time, before being woven into cloth, it becomes hard, brittle, and comparatively inflexible. It is then tedious and troubleſome to weave, and the cloth is rough, wiry, and uneven. This is chiefly remarked in dry weather, when the weavers of fine cloth find it neceſſary to work up their yarn as ſpeedily as poſſible, after it is dreſſed. To counteract this inconveniency, herring or beef brine, and other ſaline ſubſtances which attract moiſture, are ſometimes mixed in ſmall quantities with the dreſſing: but this has not been completely and generally ſucceſsful; probably, becauſe the proportions have not been ſufficiently attended to; for a ſuperabundance of moiſture is equally prejudicial with a deficiency. The variations of the moiſture of the air are ſo great and frequent, that it is impoſſible to fix any univerſal rule for the quantity of ſalt to be mixed. Some weavers put butter-milk in the paſte.

To apply the dreſſing, the weaver muſt ſuſpend the operation of weaving, whenever he has worked up that quantity of warp which he has dreſſed, or within two or three inches; he then quits his ſeat, and applies the comb to clear away knots and burs; next puſhes back the leaſe-rods towards the yarn-roll, one at a time, and if they ſlide freely between the yarns, it ſhews they are clear from knots; he then bruſhes the yarn with the paſte by two bruſhes, holding one in each hand. The ſuperfluous humidity is afterwards dried by fanning the yarns with a large fan, and then a ſmall quantity of greaſe is bruſhed over the yarn; the leaſe-rods are returned to their proper poſition, and the weaving is reſumed.

Dreſſing is of the firſt importance in weaving warps ſpun from flax or cotton; for it is impoſſible to produce work of a good quality, unleſs care be uſed in dreſſing the warp.

The ſame practice, when uſed upon ſilk, has a very deſtructive tendency: it injures the colours of the ſilk when uſed, as it is ſometimes very improperly, by the weavers of white ſatin. The injury done to the work is irreparable. In cotton, the operation of dreſſing is indiſpenſable; but in ſilk, this is by no means the caſe.

The preparation of paſte or ſize for warp, has been the ſubject of ſeveral patents. Mr. Foden, in 1799, recommends a quantity of calcined gypſum, or plaſter of Paris, to be reduced to a very fine powder, and then mixed with alum, ſugar, and the farina or ſtarch of potatoes, or any other vegetable farina. This powder, when mixed well with cold water, forms a ſoft paſte, to which boiling water is to be added, and the mixture thoroughly ſtirred till it becomes ſufficiently gelatinous for uſe.

Another ſize, for which Mr. Wilks had a patent in 1801, is prepared as follows:—The ſtarch or flour is to be extracted from any kind of potatoes which are mealy when boiled, by grating them while raw (but waſhed clean) into a tub of water. The water, thus impregnated with the grated potatoes, is run through a ſieve or ſtrainer, which will retain the coarſer and fibrous parts of the potatoes, but admit the finer particles, conſtituting the ſtarch or flour, to paſs with the water into a veſſel beneath the ſieve or ſtrainer. This water muſt remain in the veſſel ſeveral hours undiſturbed, to permit the ſtarch to ſubſide to the bottom; then the water is poured off, and the ſtarch ſo obtained is put into freſh water, and paſſed through a finer ſieve into another tub, where the ſtarch is left to ſubſide to the bottom as before, and the water is again poured off.

About two-thirds the quantity of potatoes, which furniſhed the ſtarch, are alſo to be boiled without peeling, ſo as to make them mealy when boiled; they are then maſhed, and diluted with water, ſo that they will paſs through a ſieve into a boiler. In this the maſhed potatoes are heated till they almoſt boil; and the ſtarch from the grated potatoes is then to be added, and the whole boiled and ſtirred for 20 minutes, when it will become paſte proper for uſe. It ſhould be ſpread in a flat open veſſel to cool.

Improved Syſtem of Weaving by Machinery.—In our article Cotton we mentioned that weaving-looms, worked by mechanical power, were then coming into uſe: ſince the time that article was printed theſe have made great advances; but to uſe them with advantage, the preparatory proceſſes of warping and dreſſing muſt be conducted in a particular manner. Many attempts have been made to diminiſh the number of operations through which the yarn muſt paſs by combining ſeveral together. Mr. Stuart had a patent in 1800 for ſizing or ſtarching cotton-yarn whilſt in the cop, ſo that it would be ready to warp at once. Mr. Marſland had a patent in 1805 for the ſame object: his plan was to expoſe the cops of cotton to the action of the hot ſtarch in an exhauſted receiver; the preſſure of the atmoſphere being thus removed, the ſize penetrated readily to the centre. It was found difficult to dry the cop perfectly, and the threads were ſometimes ſo glued together as to render the winding off difficult.

Another plan has therefore been introduced both for flax and cotton: this is to wind off the yarn from the cop or bobbin in which it is ſpun, and gather it upon the bobbins ready for the warping; by this manner the reeling is ſaved. A ſmall quantity of ſtarch is applied to the yarn during the operation, by cauſing it to paſs over a horizontal wooden cylinder, which revolves on its axis in a trough filled with fluid ſtarch. The threads, in paſſing from the cop to the bobbin, are drawn over the upper ſurface of the cylinder, and receive the ſtarch with which it is covered. The winding machine for this actuated a great number of bobbins at once; the warping is then conducted, as we have before deſcribed, and the dreſſing is performed in the loom whilſt weaving, that is, if woven by hand; but for the power-loom it is dreſſed previouſly to placing it in the loom.

Dreſſing Machines.—Mr. Johnſon, of Stockport, had a patent, in 1804, for a method of dreſſing whole webs of warp at

once, by a machine. The yarns were wound off from the bobbins or cops of the ſpinning machines upon beams or rollers. Several of theſe rollers were placed parallel to each other, in an horizontal direction, at the oppoſite ends of the machine, from three to ſix at each end; and the yarns from them were all combined together in one web, which was received and rolled up on the yarn-beam of the loom placed in the middle of the machine, and raiſed up conſiderably above the other rollers, ſo that the yarns proceeded from both ends of the machine towards the middle. In their paſſage they paſſed through ſeveral reeds to keep them ſeparate, and were ſupplied with the paſte by paſſing over two cylinders revolving in a trough of fluid paſte. This paſte was dreſſed or worked into the yarn by means of two bruſhes, of a length equal to the breadth of the web; one of the bruſhes acted upon the upper ſide of the yarns, and the other on the lower ſide. A ſimilar pair of bruſhes were applied at both ends; each bruſh had a motion given to it by means of cranks, exactly ſimilar to the movement with which the weaver bruſhes the yarn in the loom. Near the yarn-roller a fan was placed, like that uſed in a winnowing machine, which blew a current of air through the yarns of the warp to dry them before they were rolled up by the beam. To preſerve the leaſe, the yarns were conducted through a pair of heddles, ſimilar to thoſe of the loom, but they remained ſlack to avoid friction. The machine was moved by the mill with a conſtant and regular movement.

When a warp is thus warped, beamed, and dreſſed, the yarn-beam is carried to a loom, on which the yarn is juſt exhauſted, and is made to replace the empty yarn-roll. The ends of the yarn are joined to the old yarns by twiſting, and are thus drawn through the heddles and reed, ſo that the weaving can be reſumed with very little loſs of time, and the weaver can proceed with his work without any interruption for dreſſing. The principal objection to the above machine is the friction which the yarns muſt undergo in bruſhing, and in paſſing through ſo many reeds: it was, however, practiſed in a large work at Stockport; but the weaving was performed by hand.

Another dreſſing machine was invented by Mr. M'Adam, and he obtained a patent in 1806: it is practiſed by Mr. Monteith, at Pollockſhaws near Glaſgow. This machine is very much like the former in its manner of action. Inſtead of uſing three, four, or ſix beams at each end of the machine, there are only two beams, each containing one half the number of yarns for the intended warp. The ſtarch is ſupplied in the ſame manner as the former, or ſometimes by making the two yarn-beams themſelves turn in a trough of ſtarch without employing a ſeparate cylinder. The bruſhing is performed in a more ſimple and effectual manner by uſing cylindrical bruſhes, which revolve with a regular motion, two of them are applied on the upper ſide of the warp, and two on the lower ſide; alſo four fanners are applied to dry the warp inſtead of one. The yarns were conducted between reeds and through heddles, like the firſt machine; and hence the ſame objection of friction applies to both.

Mr. Duncan, in his Eſſays on Weaving, deſcribes another method of dreſſing warps, which is practiſed by Mr. Dunlop at Barrowfield. In this the yarn is warped and beamed in the uſual manner, upon a yarn-roll: from this the yarn is unwound, and taken up upon another beam; and in its paſſage from one to the other it is extended, ſo that the picking and clearing can be performed in the uſual way by hand with a comb and ſciſſors, and the dreſſing is applied with bruſhes in the uſual way: beneath the warp a fan is placed, to blow a current of air up through the yarns and dry them. In this machine all the operations, except the fanning, are performed by hand; the advantage, therefore, conſiſts only in the diviſion of labour, by making the dreſſing and weaving diſtinct operations.

Power-Looms.—In the article Cotton we have mentioned Mr. Dolignon's claim to the invention of weaving by mechanical power.

The original project, we believe, was by M. De Gennes, and is publiſhed in the Philoſophical Tranſactions for 1768, N° 140. See alſo Lowthorp's Abridgment, vol. i. p. 499. This is a very ingenious invention. The fly-ſhuttle was not then invented, and he ſupplied the want of it by a contrivance which held the ſhuttle as it were in a hand by fingers; this carried it half way through the cloth, and then it was transferred to another ſimilar hand, which drew it through the remainder. By this means there was a greater certainty than in throwing the ſhuttle from one ſide to the other, becauſe the ſhuttle always continued engaged with the mechaniſm: the whole machine is ingenious and worthy of notice.

M. Vaucanſon, the celebrated French mechaniſt, made a machine for weaving ten ribbands at a time, which was worked by a circular motion given by the workman; and it might, therefore, have been worked by mechanical power. This is deſcribed in the Encyclopede Methodique in great detail, with ten folding plates, and is an ingenious machine.

We believe both theſe inventions were prior to that of Mr. Dolignon; and alſo that the merit of inventing the machine, and firſt reducing it to practice, is due to Mr. Auſtin, of Glaſgow. In this gentleman's memoir to the Society of Arts, he ſtates, that his firſt attempt was made in the year 1789, when he entered a caveat for a patent, but did not apply for it further; ſince that time he made many improvements upon the original plan. In 1796 a report in its favour was made by the Chamber of Commerce and Manufactures at Glaſgow; and in 1798, a loom was ſet at work at Mr. J. Monteith's ſpinning works, at Pollockſhaws near Glaſgow, which anſwered the purpoſe ſo well, that a building was erected by Mr. Monteith for containing thirty looms, and afterwards another to hold about two hundred.

Mr. Auſtin's Power-Loom.—The model from which our drawing (*Plate* I. *Weaving*) was made, is depoſited in the Society of Arts: it is an improvement upon the looms conſtructed for Mr. Monteith.

The drawing *Plate* I. is a perſpective view, exhibiting the whole loom at one glance: it is viewed from the back rather than from the front.

A is a ſquare iron axis extending through the whole length of the machine; to this the power of the firſt mover is applied by a cog-wheel B, of thirty-ſix teeth, turned by a pinion of twelve leaves fixed to the axis of the fly-wheel D. A handle is fixed to one of the arms of the wheel to give motion to the model; but in the large machine a live and dead pulley are adapted to the axis of the fly-wheel; and by means of an endleſs ſtrap, the power is communicated from any convenient part of the mill in which a great number of looms are placed together.

The axis A has ſeveral eccentric wheels or camms fixed upon it; as theſe revolve they give motion to a number of levers or treadles, by which all the uſual operations of the loom are performed at the proper intervals: theſe are,

Firſt, To ſeparate the two parts of the yarns of the warp, as ſhewn at G, and admit of the paſſage of the ſhuttle.

Secondly, To throw the ſhuttle, in order to lay the weft or croſs-threads of the cloth.

Thirdly, To move the lay 7.8, and return it; ſo that the reed *g* will beat up the weft cloſe to the fell, or pre-

ceding ſhoot of the weft: this renders the cloth of uniform texture.

Fourthly, To wind up the cloth upon the cloth-roll, as faſt as it is formed by the preceding operations.

The yarns, which are to form the warp of the cloth, are warped in the manner before deſcribed upon the yarn-roll F; and from thence they are extended horizontally to the cloth-roll E, of which only a ſmall part can be ſeen at the oppoſite ſide of the loom: in their way the yarns paſs through the eyes of the heddles G H, which effect the firſt operation above-mentioned. Each heddle is compoſed of a number of perpendicular threads equal to half the number of yarns in the warp; theſe are ſtretched between two ſmall rods *a a* and *b b*, and in the middle of each thread is a ſmall eye, through which a yarn of the warp is paſſed; thus, the firſt yarn of the warp is paſſed through the eye of the heddle G, but has no connection with the heddle H, becauſe it paſſes between its threads. The ſecond yarn is put through the eye of the heddle H, but has no connection with G; the third yarn is attached to H; the fourth to G, and ſo on alternately throughout the whole number. By this means if one heddle is raiſed up, and the other at the ſame time depreſſed, a ſeparation of the yarns will take place as ſhewn at G, every other yarn being raiſed up, whilſt the intermediate ones are drawn down, ſo as to admit the paſſage of the ſhuttle and weft between them.

The two heddles are moved by camms upon the main axis A; and they are ſo connected by ſhort levers I I, which are ſuſpended from the upper part of the loom, that when one heddle is pulled down, the other will be drawn up at the ſame time, becauſe they are ſuſpended from the oppoſite ends of the levers I.

The camms on the main axis for the heddles are marked L; the two are exactly ſimilar, but are reverſed upon the axis; that is, the ſhorteſt radius of one is placed on the ſame ſide with the longeſt of the other. They act upon two levers, which are the ſame as the treadles in a common loom; only one of theſe treadles or levers (*viz.* that which belongs to the camm L) can be ſeen at M, the other lever being concealed from the view; both levers move on centres at *n* between the ſmall uprights *d d*; the other ends ſlide freely up and down between ſimilar uprights at the oppoſite ſide of the frame, which cannot be ſeen in the figure; the levers are connected with the heddles, which being ſuſpended from the levers I as before mentioned, the levers will therefore move in contrary directions, the one riſing when the other is preſſed down by the action of the camm on the axis A.

The connection between the levers or treadles M and the heddles G H, is made by cords communicating with two counter-levers O P, which are centered in uprights ſupported by the frame at the ends of the machine. The counter-levers O P are connected with rods *h* and *k*, and theſe by a double cord are attached to the heddle-rods *a a* and *b b*.

This machinery which we have now deſcribed effects the ſeparation of the warp thus: when the axis A turns round, every revolution of its camms L will cauſe two ſeparations of the warp, and each one in a different manner, for thoſe yarns which are raiſed up at one time are drawn down the next.

The ſecond operation, *viz.* throwing the ſhuttle, is performed by two camms R S, which are reverſed to each other upon the axis A. They act upon two levers, only one of which can be ſeen at T; they are placed beneath the camms. The ſhuttle requires to be projected with a ſudden jerk; theſe levers are therefore centered at *d* on the ſame pin as the levers M and N, but the other ends preſs down ſmaller levers W, which are centered at the oppoſite end of the frame, and lie beneath the long levers. The extreme ends of theſe ſmaller levers are connected by a ſtrap *f* with a ſegment of a wheel, which has a long ſtem of whalebone Y faſtened to it; and by means of two ſtrings, one of which is ſhewn at *q* 4, it moves the peckers or drivers *z* upon the wires 3, 3, and throws the ſhuttle. The ſhuttle, which is ſhewn in a ſeparate figure, is pointed at each end, and ſhod with iron: it contains two ſmall rollers 31 31 upon which it runs; and as they project through both ſurfaces, it will run either way upwards, or either end firſt. In the centre of the ſhuttle is an oblong mortiſe, containing the pirn or bobbin 33, on which the thread for the weft of the cloth is wound; and the end of the weft marked 34, is brought through a ſmall glaſs tube, called the eye of the ſhuttle.

The action of the mechaniſm for throwing the ſhuttle is as follows:—By the revolution of the camm R, the long lever beneath it is depreſſed, and at the ſame time the extremity of the ſhorter lever W deſcends, but with an increaſed velocity; this by means of the ſtrap *f* turns the ſegment of a wheel on its centre, and its tail Y ſnatches the ſtring *q* 4 of the pecker *z*, and makes it ſtrike againſt the ſhuttle with ſuch a velocity, as to drive the ſhuttle out of the trough Q, acroſs the ſhuttle-race, into the oppoſite trough, where it will puſh back the pecker, and remain at reſt in the trough ready for the next ſtroke: by this ſtroke it will be returned back again with an action ſimilar to the laſt, but occaſioned by the other camm S, and its correſponding levers.

The threads of the warp, which are loweſt when the ſeparation takes place, are drawn down by their heddle G or H, ſo as to lie cloſe upon the ſhuttle-race, and cauſe no obſtruction to the paſſage of the ſhuttle. To facilitate this, the ſhuttle muſt be very ſmooth on the ſurface, that it may not catch the threads and be ſtopped. The ſhuttle-race is inclined towards the reed, both that the yarn may lie flat upon it, and that the ſhuttle may not be liable to run off its race; for as it leaves the weft, which is drawn off from its bobbin, in the ſpace between the divided yarns of the warp, it might be drawn off its race ſideways, without this precaution. In this manner the ſecond operation is performed.

The third motion is that of the reed *g*: this is fixed cloſe behind the ſhuttle-race, and is a frame containing a great number of parallel ſlips of reed or cane; between theſe the yarns of the warp paſs, and when the whole frame of reeds is moved towards the cloth-roll E, they will act in the manner of a comb, to beat up the thread of the weft, which is left by the ſhuttle lying looſely between the yarns of the warp.

For this purpoſe, the ſhuttle-race, reeds, peckers, &c. and their ſtem Y, with its ſegment of a wheel, are all placed on a framer which moves on hinges at the lower ends, 8, of the two upright ſides 7 8. This frame, which is termed the lay, is drawn backwards by means of ſtraps 10, 10, rolled upon pulleys 11, faſtened upon the axis 12; upon this ſame axis are two other ſmaller pulleys, upon which two ſtraps, 13, are rolled, to connect with the long levers 14, which are moved by the camms 15, upon the axis A.

The long levers, 14, are centered at one end of the frame, and the pulleys on the axis, 12, being of different diameters, the motion of the reeds will be performed very quickly. To move the lay in a contrary direction, and give the ſtroke to beat up the weft, two large weights, like *m*, are ſuſpended by ſtraps from pulleys on an horizontal axis, which carries two larger wheels *x*; on theſe, ſtraps are wound, to commu-

nicate with the upright fides, 7 8, of the lay, and draw it forwards.

When the loom is acting very quickly, thefe weights would not act with fufficient fharpnefs to throw the reeds againft the threads of the weft with the proper force.

The weights are therefore connected by fpiral wire-fprings, with long levers 16, which are preffed down by a camm or rather tappet 17, fixed on the main axis. Thefe levers act before the lay is at liberty to move, and by preffing down the levers extend the fprings; confequently, as foon as the camm 15 fuffers the lever 14 to rife, the fprings act inftantaneoufly, to throw the lay and the reeds forwards to beat up the weft.

The inftant after the blow has been given, the lay is drawn back again by the camm 15, and returned into the vertical pofition, in which fituation the lay muft continue whilft the fhuttle is thrown; for this purpofe, the outfides of the camms 15 are portions of circles. This completes the third motion.

As faft as the cloth is fabricated by the foregoing movements, it is gathered upon the cloth-roll E. This is turned flowly round by a fmall crank 19, on the extreme end of the main axis A; the crank moves a fmall rod 20 up and down, in order to turn a fmall ratchet-wheel round one tooth each revolution of the main axis; the return of the ratchet is prevented by a click. On the axis 21 of the ratchet-wheel is an endlefs fcrew, to engage the teeth of a cog-wheel upon the end of the cloth-roll, and give it a flow motion.

The yarn is kept to a proper degree of tenfion by the friction occafioned by a line 28 paffed twice round the yarn-roll, one end being faftened to the frame, and the other to a lever 30, loaded with a weight.

The framing of the loom is too evident to need defcription. In the conftruction of the machine, the principal circumftance to be attended to, is the figure of the different camms; alfo that they are placed upon the axis A in the proper pofitions relative to each other. Thefe cautions will enfure the accurate performance of the machine.

The camm R or S, for throwing the fhuttle, is formed with a fudden beak or projection, that it may ftrike the levers T down inftantaneoufly, and throw the fhuttle; from this beak the curve continues circular for fome diftance, that the lever may be held ftationary; the remainder of the camm gradually diminifhes its radius like a fpiral, and quits the lever, in order to leave it at liberty to rife up when its correfponding lever is forced down by the beak of the other fimilar camm S.

The camm L for the heddles is made circular where it is to come in contact with the lever, and which is all the time it is in action. This occafions the levers and heddles to be ftationary whilft the fhuttle is thrown.

The inventor ftates that, by the addition of fome fimple improvements, his looms have the following advantages; *viz.* 300 or 400 of them may be worked by one water-wheel, or fteam-engine, all of which will weave cloth in a fuperior manner to what can be done in the common way. They will go at the rate of 60 fhoots in a minute, making two yards height of what is called a nine hundred web in an hour. They will keep regular time in working, ftop and begin again, as quick as a ftop-watch. They will keep conftantly going, except at the time of fhifting two fhuttles, when the weft on the pirns is exhaufted. In general, no knots need be tied, and never more than one in place of two, which are requifite in the common way when a thread breaks. In cafe the fhuttle ftops in the fhed, the lay will not come forwards, and the loom will inftantly ftop working. They will weave proportionally flower or quicker, according to the breadth and quality of the web, which may be the broadeft now made. They may be mounted with a harnefs or fpot-heddles, to weave any pattern, twilled, ftriped, &c.

There is but one clofe fhed, the fame in both breadths, and the ftrain of the working has no effect on the yarn behind the rods.

The fell and temples always keep the fame proper diftance. There is no time loft in looming, or cutting out the cloth; but it is done while the loom is working, after the firft time.

The weft is well ftretched, and exactly even to the fabric required.

Every piece of cloth is meafured to a ftraw's breadth, and marked where to be cut at any given length.

The loom will work backwards in cafe of any accident, or of one or more fhoots miffing. Every thread is as regular on the yarn-beam as in the cloth, having no more than two threads in the runner. If a thread fhould appear too coarfe or fine in the web, it can be changed, or any ftripe altered at pleafure. They will weave the fineft yarn more tenderly and regularly than any weaver can do with his hands and feet.

When a thread, either of warp or weft, breaks in it, the loom will inftantly ftop, without ftopping any other loom, and will give warning by the ringing of a bell. A loom of this kind occupies only the fame fpace as a common loom; the expence of it will be about half more; but this additional expence is more than compenfated by the various additional machinery employed for preparing the yarn for the common loom, and which this loom renders entirely unneceffary.

The preparatory proceffes of reeling, winding, warping, beaming, and looming, and the interruptions occafioned by combing, dreffing, fanning, greafing, drawing bores, fhifting heddles, rods, and temples, which is nearly one-half of the weaver's work, do not happen in thefe looms. The general wafte accompanying the above operations is ftated at about fix *per cent.* of the value of the yarn, all which occur in the operations of the common loom. The power-loom, without further trouble, performs every operation after the fpinning, till the making of the cloth is accomplifhed, by which a faving is effected of about 20 *per cent.* of the yarn.

The heddles, reed, and brufhes, will wear longer than ufual, from the regularity of their motion. More than one-half of workmanfhip will be faved; one weaver and a boy being quite fufficient to manage five looms of coarfe work, and three or four in fine work.

Mr. Miller's Power-Loom.—A patent was taken out for this in 1796. It is fo much like Mr. Auftin's in its general principle, that it is unneceffary to enter into the defcription. The motions are all produced by camms fixed on a horizontal axis, and operate upon a number of horizontal levers, difpofed beneath the loom, in the fituation of treadles: in other refpects the arrangement of the parts is very different. This is fometimes called the wiper-loom, wiper being a different name for a camm.

Crank Loom by Power.—In this the treadles are actuated by cranks, inftead of camms or wipers. The reciprocating motion produced by a crank is not uniform, but accelerated at one time, and retarded at another. This is an advantage in fome of the operations of a loom. It is true, that, by means of wipers, any required law of acceleration may be produced; but in a crank, the acceleration muft proceed according to one law. The fuperiority of cranks arifes

from the circumſtance, that they will communicate motion in both directions; whereas a camm will only puſh a lever in one direction, and the return of the motion muſt be made by a ſpring or counterweight. Now, if this counterweight is too large, it makes unneceſſary loſs of power and friction; and if it is too ſmall, there is ſome uncertainty in the return of the lever.

Mr. Todd of Boulton had a patent, in 1803, for improvements in power-looms.

Mr. Horrocks of Stockport had three ſucceſſive patents for this kind of machinery, in 1803, 1805, and 1813. The machine deſcribed in the latter is a crank-loom; that is, the lay is actuated by a crank to beat up the weft. The principal improvement conſiſts in a ſyſtem of levers, which tranſmit the action of this crank to the lay, and ſo modify it, that the lay will advance quickly, and give an effective ſtroke to the weft, and then withdraw quickly to a ſtationary poſition, in which it will remain whilſt the ſhuttle is thrown. The advantages which are ſtated are, that a large ſhuttle may be uſed, ſufficient to hold a full-ſized cop of weft: the waſte and loſs of time by renewing the cop will, therefore, be leſs. From the ſmartneſs of the ſtroke, leſs weight will be required on the yarn-beam, and this will occaſion the heddles to work more lightly, ſo as to break fewer threads. From the ſame cauſe, more threads of the weft may be laid in an inch, and make cloſer work.

Mr. Johnſon of Preſton had a patent in 1805, and another in 1807, for a power-loom, in which the warp is ſtretched on a vertical plane, inſtead of horizontal, as in former machines. The advantages of this are ſtated to be, 1ſt, that it takes leſs ſpace; 2d, the reed ſerves for the ſhuttle-race, becauſe the ſhuttle runs upon the reed itſelf, and, therefore, makes no friction upon the yarns; 3d, alſo in dreſſing, picking, and clearing the warp, the attendant always remains in front of the machine, and can continue to watch the machine; whereas, in the other looms, he muſt quit his poſt in front, and go round behind the looms for theſe operations. When the dreſſing is to be applied to the warp, whilſt it is in the loom, that part of the warp is conducted horizontally for that purpoſe, and a fan is applied to dry the warp.

The lateſt inventions of power-looms are Mr. Peter Ewart's patent, 1813; and Mr. Duncan's loom, which he calls a vibrating loom.

The Indian Loom.—This is a ſtriking contraſt to our power-looms; it conſiſts merely of two bamboo rollers, one for the warp, and the other for the finiſhed cloth; and a pair of heddles. The ſhuttle performs the double office of ſhuttle and reed: for this purpoſe, it is made like a large netting-needle, and of a length ſomewhat exceeding the breadth of the piece of cloth which is to be woven.

This apparatus the weaver carries to any tree which affords a ſhade moſt grateful to him: under this he digs a hole large enough to contain his legs, and the lower part of the geer or heddles; he then ſtretches his warp, by faſtening his bamboo rollers at a due diſtance from each other on the turf, by wooden pins; the balances of the geer or heddles he faſtens to ſome convenient branch of the tree over his head; and two loops underneath the geer, in which he inſerts his great toes, ſerve inſtead of treadles; his long ſhuttle, which performs alſo the office of a batten, draws the weft, throws the warp, and afterwards ſtrikes it up cloſe to the web. In ſuch looms as this are made thoſe admirable muſlins, whoſe delicate texture the Europeans can never equal, with all their complicated machinery.

The weaving, even of their fineſt muſlins, is thus conducted in the open air, expoſed to all the intenſe heat of their climate. We know well that this would be impracticable with fine work in this country, even in an ordinary ſummer day, on account of the ſudden drying of the dreſſing. It is not known what is the ſubſtance which the Indian weavers employ for dreſſing their warps. It might be of uſe to our manufacturers, were this inveſtigated in a ſatisfactory manner. It is ſaid to be a decoction of rice, formed by boiling the rice in a ſmall quantity of water, and expreſſing the juice: when this is cool, it forms a thick glutinous ſubſtance, which undergoes ſome kind of fermentation before it is uſed.

Figure-weaving.—Having given an account of the nature and proceſs of plain weaving, we muſt notice the fanciful and ornamental parts of the buſineſs. The extent to which this ſpecies of manufacture is carried renders it an object of very great national importance, and deſerving a more minute deſcription than our limits will admit.

Figures or patterns are produced in cloth, by employing threads of different colours, or of different appearance, in the warp, or in the weft. By the weaving, the threads muſt be ſo diſpoſed, that ſome colours will be concealed and kept at the back, whilſt others are kept in the front; and they muſt occaſionally change places, ſo as to ſhew as much of each colour, and as often as it is neceſſary, to make out the figure or pattern.

The weaver has three means of effecting ſuch changes of colour: Firſt, by uſing different coloured threads in the warp, or threads of different ſizes and ſubſtances; theſe are arranged in the warping, and require no change in the manner of weaving. This is confined to ſtriped patterns, the ſtripes being in the direction of the length of the piece.

Secondly, by employing ſeveral ſhuttles charged with threads of different colours or ſubſtances, and changing one for another every time a change of colour is required. This makes ſtripes acroſs the breadth of the piece; or, when it is combined with a coloured warp, it makes chequered and ſpotted patterns of great variety.

Thirdly, by employing a variety of heddles, inſtead of two, as we have hitherto deſcribed; each heddle having a certain portion of the warp allotted to it, and provided with a treadle. When this treadle is depreſſed, only a certain portion of yarns which belong to that heddle will be drawn up, and the reſt will be depreſſed; conſequently, when the weft is thrown, all thoſe yarns which are drawn up will appear on the front or top of the cloth; but in the intervals between them, the weft muſt appear over thoſe threads which are depreſſed. The number of threads which are thus brought up may be varied as often as the weaver chooſes to preſs his foot upon a different treadle, and by this he produces his pattern.

All theſe means may be combined together, and give the weaver the means of repreſenting the moſt complicated patterns.

The principal varieties of woven cloth, including only thoſe which require a different proceſs for their fabrication, are the following:

Stripes are formed upon the cloth either by the warp or by the woof. When the former of theſe ways is practiſed, the variation of the proceſs is chiefly the buſineſs of the warper; but in the latter caſe, it is that of the weaver, as he muſt continually change his ſhuttle.

By unravelling any ſhred of ſtriped cloth, it may eaſily be diſcovered whether the ſtripes have been produced by the operation of the warper or thoſe of the weaver.

When the fly-ſhuttle is uſed, the changing of the ſhuttle is very readily effected by a ſimple contrivance. One of the ſhuttle-boxes or troughs, as we have before called them,

(*Plate* II. *Weaving*, *fig.* 2.) is made in two parts, so that a part of the trough I near the pecker, where the shuttle lies during the time it is at rest, can be removed, and another trough substituted, which contains a different shuttle. For the purpose of making the change with facility, a moveable shuttle-box *n* is suspended by two perpendicular stems *o* from a wire or centre of motion *m* attached to the lay, as is shewn by the dotted lines. The moveable box is just on the same level with the shuttle-trough I, and is divided by partitions into two or three separate troughs, each exactly the width of the regular trough, and as long as is necessary to contain a shuttle. The pecker *k*, and the wire upon which it slides, remain exactly as before described; but by swinging the moveable box *n* on its centre any one of its compartments may be brought to line with the real place for the shuttle-trough in which the pecker runs. The moveable box must have proper catches to hold it exactly in its true positions.

In working with this contrivance a shuttle of a different colour must be placed in each cell or division of the moveable box *n*; and when the weaver desires to change the shuttle he pulls the connecting string. This moves the shuttle-troughs either backwards or forwards, so as to carry away that shuttle which had been just before in use, and place another before the pecker. Then if he pulls the pecker-handle *y* the new shuttle will be thrown across the shuttle-race, just as the old one was in the former instance. If only one moveable shuttle-box is used there will be some limitation in the pattern, because the stripes of different colour must always consist of an even number of the same coloured thread, as two, four, six, &c. This may be obviated, and a greater change of shuttles may be introduced, by using two moveable shuttle-boxes, one at each end of the shuttle-race: in that case the two moveable boxes are provided with cranks and strings, so that the weaver can reach either of them with ease.

Checks are produced by the combined operations of the warper and the weaver.

Tweeled cloths are so various in their textures, and so complicated in their formation, that it is difficult to convey an adequate idea of the mode of constructing them without the aid of several drawings.

In examining any piece of plain cloth, it will be observed that every thread of the weft crosses alternately over and then under every thread of the warp which it comes to; and the same may be said of the warp: in short, the threads of the warp and weft are thus interwoven at every point where they cross each other, and are therefore tacked alternately.

Tweeled cloth is rather different, for only the third, fourth, fifth, sixth, &c. threads cross each other, to form the texture.

Hence two, three, four, or more, of the successive threads or shoots of the weft will be found to pass under or over the same thread of the warp; or, in other words, by tracing any thread of the warp it will be found to pass over two, three, four, or more threads of the woof at once, without any interweaving the warp. Then it crosses and passes between the threads of the weft, and proceeds beneath two, three, four, or more threads, before it makes another passage between the threads of the weft.

Tweeled cloths are of various descriptions, and produce different kinds of patterns; because at all the intersecting points where the threads actually cross or interweave both threads of warp and weft are seen together, and these points are therefore more marked to the eye, even if the warp and weft are of the same colour. These points in plain tweels form parallel lines extending diagonally across the breadth of the cloth, with a different degree of obliquity, according to the number of weft-threads over or under which the warp-threads pass before an intersection takes place. In the coarsest kinds every third thread is crossed: in finer fabrics they cross each other at intervals of four, five, six, seven, or eight threads; and in some very fine tweeled silks the crossing does not take place until the sixteenth interval.

Tweeling is produced by multiplying and varying the number of heddles, or, as the weavers express it, the number of leases in the harness, which is the name given to the whole number of heddles employed in a loom; by the use of a back-harness or double-harness, by increasing the number of threads which pass through each split of the reed, and by an endless variety of modes in drawing the yarns through the heddles; also by increasing the number of treadles, and changing the manner of treading them.

The number of treadles requisite to raise all the heddles which must be used to produce very extensive patterns, would be more than one man could manage; for if he placed his foot by mistake on a wrong treadle he would disfigure his pattern. In these cases, recourse is had to a mode of mounting or preparing the loom, by the application of cords to the different heddles of the harness; and a second person is employed to raise the heddles in the order required, by pulling the strings attached to the respective heddles of the back-harness, and each heddle is returned to its first position by means of a leaden weight underneath. This is the most comprehensive apparatus used by weavers, for all fanciful patterns of great extent, and it is called the Draw-*Loom*. See that article.

The manner of mounting the harness of looms, to produce all the principal varieties of fabrics, is detailed in our articles Design, Draught, and Cording *of Looms*; also Damask, Diaper, Dimity, Dornock, Fustian, and Tapestry. A perusal of those articles will render it unnecessary for us to proceed farther on that subject in the present article. We shall however describe a most valuable invention, which has of late years come into use, as a substitute for the second person or draw-boy, who must be employed in the draw-loom, by which loom alone all the complicated patterns can be woven.

Machine called the Draw-Boy, because it performs the Office of a Draw-Boy in Weaving.—The saving of labour is not the only advantage of this machine; the certainty of its operation and security from mistake are obvious. The weaver produces the required action upon the most complicated harness by two treadles only, which he works alternately, just with the same motion as in plain cloth-weaving. The machine, when once set up, performs every thing else.

Like most other inventions, this was at first imperfect, but has been gradually improved. We do not know its history, but we have seen great numbers of machines, for carpet-weaving and coarse goods, which have been some years in use. The machine is situated in a small square frame, not larger than a chair, which stands at the side of the loom, and cords from all the different heddles are conducted from the draw-loom down to this frame, where they are arranged in order. Each cord has a knot answering to the handle, which the boy must pull in the common draw-loom; and there is a piece of mechanism actuated by the treadles which at every stroke selects the proper cord, and draws it down so as to raise the heddles belonging to it. The next time it changes its position and takes another cord, and so on until the whole number of cords has been drawn and the pattern completed.

These original machines have a great defect, *viz.* that they only proceed with regularity to raise up all the heddles, until all the cords have been drawn, and one series of changes

has been gone through; but when this is completed, and a repetition of the pattern is wanted, the weaver must stop and restore the machine to its original position by pulling a string. This appears very easy, but it diverts his attention; and if he does not do it at the exact moment his pattern may be spoiled. This defect was remedied by Mr. Alexander Duff, who received a small and inadequate premium from the Society of Arts in 1807, probably because they were not aware of its value and importance; but in 1810 we find them with a liberality truly discouraging to real merit, giving an equal reward to another person, for the most trivial alteration of Duff's machine. The latter machine is alone described in their Transactions; see vol. xxviii.

Mr. Duff's Draw-Boy.—*Fig.* 4. *Plate* II. *Weaving*, is a plan of this machine, and *fig.* 2. a perspective view. It is fixed at the side of a draw-loom, in the same place as a draw-boy would stand, and H shew the cords which are to draw the harness. The same letters are used in both figures. A A is a square wooden axis, mounted so as to turn backwards and forwards in the frame B B, on points or centres of motion. At one end of it a pulley D is fixed, to receive a line *a a* fastened to it at the highest point, by means of which the axis receives motion from the two treadles of the loom, one of the treadles being attached to one end of the line, and the other to the opposite end of it. E E are two rails of wood, fixed across the frame parallel to the axis; and *e e* are two brass plates screwed to the rails, and pierced with a great number of holes to receive as many cords. Each cord is tied by one end to a central rail F of the frame beneath the axis; and after passing through one of the holes in the above plate *e*, and turning over a round wooden rod G, has a lead weight suspended to the other end of it. These weights are shewn at *b b*. The rods G G are suspended by strings at their ends from the ceiling of the room. To each of the above cords another is tied just before it passes over G. These are represented by H, and hang loosely. The upper ends of these cords are tied to horizontal cords extended across the ceiling of the room, and made fast to the ceiling at one end; the other ends pass over pulleys situated at the top of the loom, in a frame called the table of mullets, and the harness or heddles are suspended by them.

By this arrangement it will be seen, that when any one of the cords fastened at F is pulled down, it must draw one of the strings H, and raise such an arrangement of the harness or heddles as is proper to produce the figure which is to be woven. The weight *b* draws the cord so as to keep it straight; all that is therefore necessary is to draw down the cords at F one at a time, but to take a different one each time, and thus raise a different series of the heddles each time; this is the business of the machine, and which it accomplishes in the following manner.

The bar, or axis, A A, has an iron semicircle, *d*, grooved like a pulley, and each of its ends divided, so as to form a cleft-hook or claw.

Each of the strings made fast at F has a large knot tied in it, just beneath where it passes through the brass plate *e e*, and which knot stops the farther ascent of the cord, in consequence of the pull of the weight *b*. Now when the axis A vibrates backwards and forwards by the treadles of the loom, as before mentioned, the hook of the semicircle *d* seizes the knot of one of the cords F, and draws down that cord, and raises the heddles belonging to it. The weaver throws the shuttle, and then returns the treadles, and the axis A with the semicircle returns back again, and allows the cord F to take its original position. When the semicircle *d* inclines over to the other side, its opposite hook takes hold of the cord F, which is next to the one opposite to that which it just quitted; it draws down this cord, and the weaver again throws his shuttle, then returns the semicircle to the opposite side, and it will take the cord next to the opposite one, and so on; so that the semicircle will in succession take every alternate cord in each of the rows *e e*, and leave every other.

This is effected by the semicircle sliding along its axis A every time, by means of two wooden racks, *h* and *i*, in the plan, which are let into grooves in the axis A; these racks have teeth like saws, but inclined in contrary directions. The racks move backwards and forwards in their grooves, the extent of a tooth at each vibration of the axis, by the action of two circular inclined planes of iron fastened to the frame at L M, against which the ends of the racks are thrown by spiral springs concealed beneath each rack. The semicircle is fixed on a box or carriage N, which slides upon the axis A, and has two clicks upon it; one at *l*, which falls into the teeth of the rack *h*; the other at *m* for the rack *i*: *n* is a roller fixed over the box, and connected with the two clicks *l* and *m*, by threads wound in opposite directions; so that one click is always raised up, and disengaged from its rack, while the other is in action. O is a piece of wire fixed to the frame, so as to intercept a small wire projecting from the roller when the axis is inclined, and turn the roller a small quantity; P is another wire for the same purpose, but fixed to a cross bar, Q, which is moveable, and can be fastened at any required place, farther or nearer from the end of the axis. Suppose the roller *n* to be in such a position that the click *m* is down, and *l* drawn up, the action will be as follows: the semicircle first inclines to the direction of *fig.* 2., its hook taking down one string; during this motion the end of the rack *i* comes to the inclined part of the circular inclined plane M, and moves by its spring towards D, the space of one tooth, which the click *m* falls into. On the return of the axis, the rack *i* is thrust back, and the box N and semicircle with it towards L, causing the hook to take the next opposite string: in this manner it proceeds, advancing a tooth each vibration, till it gets to the end of its course; the tail of the roller *n* then strikes against the pin P, and turns the roller over, raises the click *m*, and lets down the other, *l*, into the teeth of the rack *h*; this was all the time moving in a contrary direction to *i*, by its inclined plane L, but had no action, as its click *l* was drawn up; this being let down, the semicircle is moved back, a tooth at a time, towards M, until it meets O, which upsets the roller *n*, and sends the semicircle back again.

Tweeled Silks.—In weaving very fine silk tweels, such as those of sixteen leases, the number of threads required to be drawn through each interval of the reed is so great, that if they were woven with a single reed, the threads would obstruct each other in rising and sinking, and the shed, or opening of the divided warp, would not be sufficiently open to allow the shuttle a free passage. To avoid this inconvenience, other reeds are placed behind that which strikes up the weft; and the warp-threads are so disposed, that those which pass through the same interval in the first reed are divided in passing through the second, and again in passing through the third. By these means the obstruction, if not entirely removed, is greatly lessened.

In the weaving of plain thick woollen cloths, to prevent obstructions of this kind arising from the closeness and roughness of the threads, only one-fourth of the warp is sunk and raised by one treadle, and a second is pressed down to complete the shed between the times when every shot of weft is thrown across.

Double Cloth is composed of two webs, each of which

confifts of feparate warps and feparate wefts, but the two are interwoven at intervals. The junction of the two webs is formed by paffing each of them occafionally through the other, fo that any particular part of both warps will be found fometimes above and fometimes below.

This fpecies of weaving is almoft exclufively confined to the manufacture of carpets in this country. The material employed is dyed woollen, and as almoft all carpets are decorated with fanciful ornaments, the colours of the two webs are different, and they are made to pafs through each other at fuch intervals as will form the patterns required. Hence it happens that the patterns at each fide of the carpet are the fame, but the colours are reverfed. Carpets are ufually woven in the draw-loom, or with the machine called the draw-boy before defcribed.

Marfeilles is a fabric woven of cotton, which is a double cloth. The loom for weaving Marfeilles is fomewhat fimilar to the diaper loom. A good idea of the manner in which it is prepared may be had, by conceiving two webs woven one under the other in the fame loom, which are made to intermingle at all the depreffed lines, and form the reticulations on the furface, in imitation of the quilting performed by hand.

When the fpecies of Marfeilles, called Marfeilles quilting, is made, a third warp, of fofter materials than the two others defcribed, lies between them, and merely ferves as a fort of ftuffing to the hollow fquares formed by them.

Quilting is another fort of cotton ftuff, folely appropriated to quilts, which fhould, in ftrictnefs, be fet down exclufively to the cotton manufacture, although there is nothing to prevent its being made of other materials.

The weft of thofe quilts is of very coarfe and thick yarn, which is drawn out by a fmall hook into little loops, as it is woven, that are fo arranged as altogether to form a regular pattern; every third or fourth fhoot of the fhuttle, the weaver has to ftop to form thofe loops from a draft, which caufes the weaving of thofe quilts to take up more time than that of any other ftuff, except tapeftry; which accounts for the greatnefs of the price at which they are fold, in proportion to the value of the materials of which they are principally compofed.

Gauze differs in its formation from other cloths, by having the threads of the warp croffed over each other, inftead of lying parallel. They are turned to the right and left alternately, and each fhot of weft preferves the twine which it has received.

This effect is caufed by a fingular mode of producing the fheds, which cannot eafily be defcribed without the aid of drawings.

Crofs, or *Net Weaving*, is a feparate branch of the art, and requires a loom particularly conftructed for the purpofe.

Spots, brocades, and lappets, are produced by a combination of the arts of plain, tweeled, and gauze weaving, and as in every other branch of the art are produced in all their varieties by different ways of forming the divifion of the warp by the application of numerous heddles, and their connections with the treadles which move them. Indeed the great fkill of the art confifts in the proper management of this part of the apparatus of a loom.

Ribband Weaving.—This was formerly performed by a fmall common loom, weaving one ribband at a time. Ribbands are commonly ftriped in the length by laying a ftriped warp, and patterns are produced by changing the colour of the weft occafionally; fometimes an ornamented edging is formed by a fucceffion of open loops at the borders of the ribband. Figured ribbands are alfo woven by a great number of treadles, but as they rarely extend to a greater number than the weaver can manage by his feet, they feldom employ a draw-loom.

Engine-Loom for weaving Ribbands.—The weavers at Coventry, which is the principal feat of the ribband trade, univerfally employ what they call an engine-loom: it is worked by the hands and feet like a common loom, but weaves twelve, fixteen, or even twenty ribbands at once. The fhuttles are of courfe fly-fhuttles, and are driven by what is called a ladder, becaufe it is a fmall frame exactly like a ladder, which flides horizontally in a groove in the lay; and every crofs-bar of the ladder acts upon one fhuttle in the manner of a pecker: the ladder has a handle to give it motion.

Another peculiarity of this loom is, that the ribbands are taken away as they are woven, with very few interruptions to wind up the work: for this purpofe they conduct the warps over pulleys, and the ribbands alfo, fo that both hang down in long loops. Thefe looped parts are conducted through pulleys, which are loaded with weights, and tend always to draw the loops down, and keep the warp tight. The weight which is thus fufpended by the finifhed ribband tends to draw it forwards at every ftroke which the lay makes; and the weight which is fufpended by the yarn of the warp is drawn up. When thefe weights have run through their refpective courfes, the weaver muft ftop to wind up the finifhed ribband, and unwind a frefh length of yarn. In fome looms this is rendered unneceffary by a fimple mechanifm, which continually winds up the ribband as faft as it is woven.

In 1801 the Society of Arts rewarded Mr. Thomas Clulow, for an improved loom for weaving figured ribbands.

This loom differs from the common figured ribband-looms in the method of forming the figure, which, in the old mode, was tedious, from the work being ftopped, whilft the figure was drawn by hand.

In the prefent loom, the tire-cords which form the figure are drawn or worked by a cord or leather-ftrap fixed to the centre-treadle, which ftrap paffes over two vertical and one horizontal pulley to the back of the loom, and has a weight hung to the end thereof. Upon this ftrap above the weight is fixed an iron, of a bevel or floping form, which when the ftrap is pulled up by preffing with the foot upon the treadle, raifes a wire-lever placed acrofs the main-wheel of the movements placed vertically, and allows this main-wheel to move one-fourth of its circumference, where it is ftopped by an iron pin, placed on its rim, and prevented from returning by a clitch or catch on the edge of the wheel on its right fide.

Within the rim of the main-wheel is a fmall catch-ftrap connected with the ftrap above-mentioned; this catch-ftrap pulls forward the main-wheel one-fourth of its circumference, until it is ftopped by the wire-lever and one of the pins on the rim, of which there are four in number in the ground.

There are alfo four iron pins projecting from the left fide of the main-wheel in oppofite quarters of it: thefe act on a hanging lever, to the lower part of which a ftring is attached, which paffes behind the box containing the whole machinery, and raifes four clicks or catches on four rollers, which permits any one of the four rollers to run back as the figure may require, each roller by fuch motion drawing up the number of threads neceffary to form the figure, by cords extending from thefe rollers over pulleys to the pafs-cords, which draw the figure.

Machine Loom for Ribbands.—We have before mentioned M. Vaucanfon's loom for weaving ten ribbands by a rotatory motion. We do not know that this is in ufe in this country.

Mr. James Birch invented an improvement on the fwivel-loom, fo as to weave fatin-guard or figured laces, and received a reward from the Society of Arts in 1804.

This loom is worked by a circular motion of the hands, without treadles, or any application of the feet.

A wooden bar, to which the hands are applied, works two cranks on a large iron axle, extending the width of the loom; one crank is near each end of the above axis. A fly-wheel is attached to one of the ends of the axis, to regulate the motion of the machinery; an endlefs fcrew is placed upon the axis, works a ftar-wheel underneath it, which turns a barrel that has a refemblance to that of a hand-organ, and has wooden pegs fixed in different parts around it: thefe pegs catch upon levers, which draw forward the cords that form the figure, and pull them down by a claw, which fecures the cords thus brought within its power, and by thofe means raife the upper geer connected with the cords.

In this loom fourteen pieces of fatin-guard or bed-lace are wove at the fame time, either one pattern and breadth, or all of different patterns and breadths, as may be required. The figure may be extended to any number of fhoots defired.

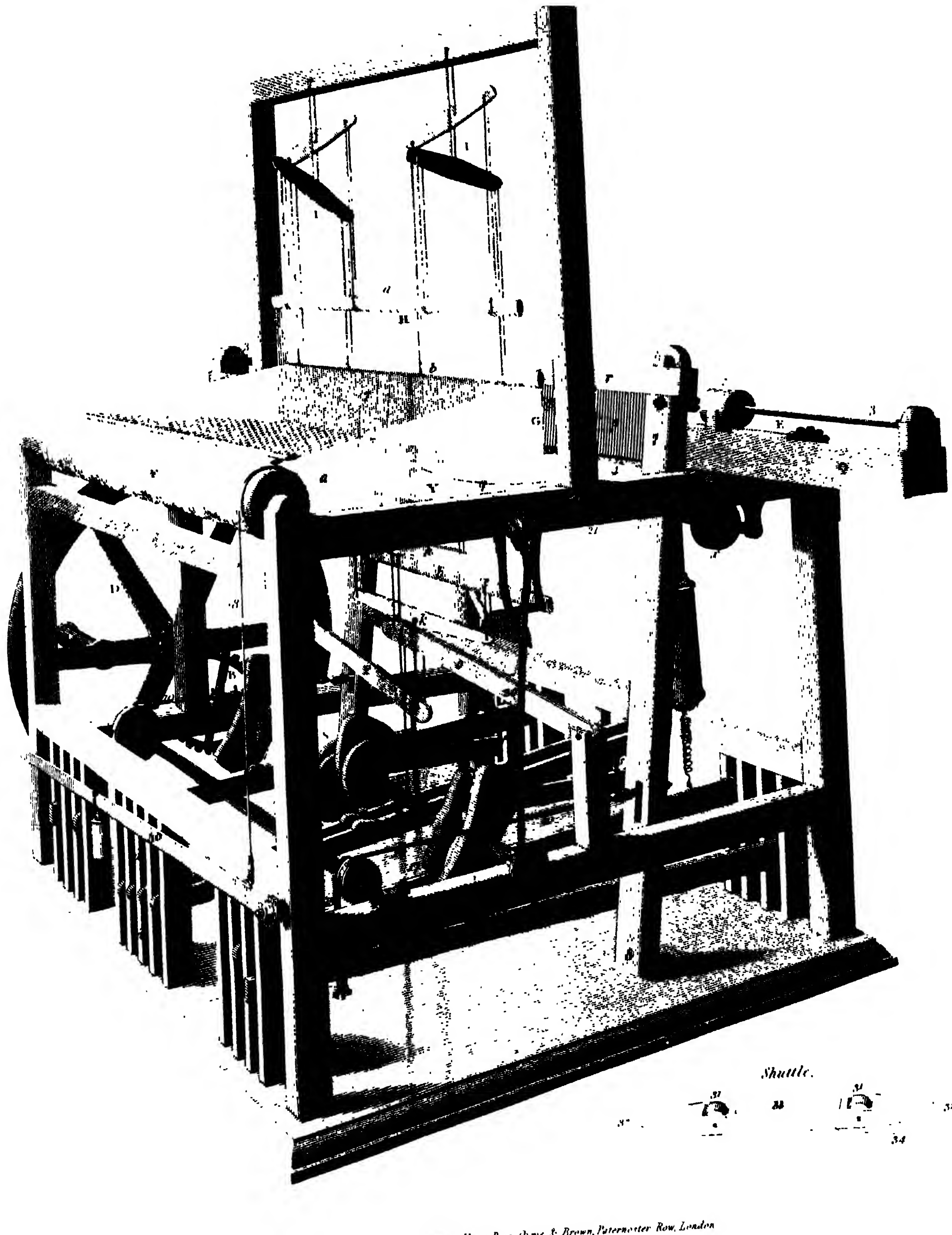
The loom takes up no more fpace than a common fwivel-loom, fuch as is employed in plain-work. It appears to work with eafe and expedition, to make good work, and to be eafily managed. It does not break or chafe the filk during its working. The weaver can move to any part of the front of the loom to infpect the work, and to continue the motion during that time; and the figure or pattern may be formed double the length of thofe ufually done in the engine-loom. The loom can be ftopped when required, at any one fhoot of the fhuttle; and it will anfwer to weave articles made of filk, wool, cotton, or linen, or mixtures of thofe articles, or gold or filver lace, and performs its work in half the time of an engine-loom.

The want of uniformity in the technical phrafeology of the art of weaving, and the intricacy of the fubject, have compelled us to render our defcriptions far more intricate and difficult than they otherwife would have been.

We muft acknowledge the affiftance which we have derived from the very excellent "Effays on the Art of Weaving," by Mr. Duncan, 1808, in 2 vols. 8vo. It is a moft curious and valuable publication, embracing almoft every thing neceffary to be known concerning the art on which it profeffes to treat; if we except fome of the recent improvements in machine-weaving, which are only flightly noticed.

The French have long excelled in the various branches of figure-weaving; but this is more from dexterity of their weavers than from their machinery. Defcriptions and drawings of all looms ufed by them, with every detail of their ftructure, will be found in the different articles of L'Encyclopede Methodique, and Les Arts et Metiers, D'Art de Fabriquer le Soie, &c.

Mr Austin's Engine Loom.



Shuttle.

J. Farey del.

Published as the Act directs 1814 by Longman, Hurst Rees, Orme & Brown, Paternoster Row, London.

Wedgwood

WEDGWOOD, Josias, in *Biography*, was the younger ſon of a Staffordſhire potter, and born in July 1730. His education was reſtricted, but his mental powers were of a ſuperior kind, ſo that by the fixed and perſevering exerciſe of them he made very conſiderable improvement in the art of pottery to which his attention was directed, and gave a name as well as reputation to the place of his nativity. (See Pottery and The Potteries.) His patrimony was ſmall, but by his ſuper-eminent ſkill and ſteady application he was the founder of his own fortune as well as fame. The principal ſeat of the potteries of Staffordſhire was Burſlem; and there is reaſon to believe that they have exiſted in or near this place for many centuries, and even, as ſome ſay, ſince the time of the Romans. But they had continued for a long time in the ſame rude ſtate in which Plot found them when he ſurveyed this county. The merit of introducing into this country improvements in the art of pottery muſt be aſcribed to two brothers of the name of Eders, who came hither from Holland about the year 1700, and ſettled in the neighbourhood of the Staffordſhire potteries. They manufactured a red unglazed porcelain from a clay, which they found in the eſtate on which they ſettled, called "Bradwell;" but this was only the brown ſtone ware, in the compoſition of which no flint is uſed; but they made uſe of ſalt in glazing it: this ſalt, or muriate of ſoda, was thrown into the oven at a certain ſtage of the firing proceſs, and the pieces of ware were ſo diſpoſed as to receive the fumes of it on every part of their ſurfaces. The fumes, however, occaſioned an alarm in the neighbourhood, which obliged them to leave the country. A ſimilar manufactory, however, was ſoon after eſtabliſhed at Shelton, in the Potteries, by one of their workmen, whoſe name was Aſtbury, and who had poſſeſſed himſelf of their ſecret; and as it was found very uſeful, it was tolerated by the inhabitants, though on the day of glazing, the denſe offenſive fumes from fifty or ſixty manufactories filled the valleys, and covered the hills through an extent of ſeveral miles. The white ſtone ware,

and the use of ground flints in pottery, were introduced at a later period, and, as it is said, (see Parkes's Chem. Catechism,) in consequence of the following incident. About the year 1720, a potter, supposed to be the above-mentioned Astbury, stopped at Dunstable in his way to London, and sought a remedy for a disorder in his horse's eyes; and the ostler of the inn by burning a flint stone reduced it to a fine powder, which he blew into them. The potter, observing the beautiful white colour of the flint after calcination, instantly thought of applying the discovery to the improvement of his art, and afterwards introduced the white pipe-clays found on the south side of Devonshire, instead of the iron-clays of his own country, and thus produced the white stone ware. At first the flints were pulverized to the great injury of the persons employed; till the famous Brindley, in the early period of his life, constructed the mills that are now used for grinding them in a moist state. It is farther said, that an ingenious mechanic, named Alsager, afterwards improved the construction of the potter's wheel, so as to give much greater precision and neatness to the work. But still the French pottery exceeded in beauty that of Staffordshire; and about the year 1760, a considerable quantity of it was imported, and purchased by persons of opulence to the great detriment of the English manufacture. Mr. Wedgwood directed his attention to this article, and made several improvements with regard to the forms, colours, and composition of his manufacture; and in the year 1763 invented a kind of ware for the table, which gave a turn to the market, and under the name of queen's ware, conferred upon it in consequence of the patronage of her majesty, came into very general use. Its materials were the whitest clays from Devonshire and Dorsetshire, mixed with ground flint, and covered with a vitreous glaze. By varying and repeating his experiments, Mr. Wedgwood discovered the mode of manufacturing other species of earthenware and porcelain, excellent and beautiful, and adapted to various purposes both of use and ornament. With a view of prosecuting his improvement in pottery he applied to the study of chemistry, and for his farther assistance engaged the ingenious Mr. Chisholme, who had been employed in a similar department by the celebrated Dr. Lewis, author of the "Commercium Philosophico-Technicum;" for whom he not only built a comfortable habitation near the manufactory, but liberally afforded him an annuity for his support under the decays of age, which he continued till his death. Aided also by the classical taste of his partner, Mr. Bentley, potteries were furnished which served as models for various articles, formed of other materials, that were held in high estimation. We learn from Dr. Bancroft, that almost all the finely diversified colours which Mr. Wedgwood applied to his pottery were produced only by the oxyds of iron. In the manufacture of his beautiful jasper ware, which rivalled the productions of antiquity, and which found its way into the collections of the curious in all parts of Europe, he employed the native sulphate of barytes, and from this use of it he derived great profit, until by the infidelity of a servant the secret was disclosed and sold, so that others employed inferior workmen at a reduced salary, and thus prevented Mr. W. from employing his exquisite modellers on that branch of the manufacture.

Among other curious productions of this inventive manufacturer we may mention his imitation of the Barberini or Portland vase, which was discovered in the tomb of Alexander Severus, and for which the late duchess of Portland paid 1000 guineas. The subscription for Mr. W.'s manufacture was at the rate of 50*l.* each for fifty vases, but such were the expences of its execution, that the partners lost money by the undertaking. Mr. Webber, it is said, received 500 guineas merely for modelling it. See VASE.

We cannot forbear in this connection noticing two cameos of Mr. Wedgwood's manufacture; one of a slave in chains, of which he distributed many hundreds, with a view of exciting the humane to assist in the abolition of the slave-trade, and the other a cameo of Hope, attended by Peace and Art and Labour, which was made of argillaceous earth from Botany Bay, to which place he sent many of them, in order to shew what their materials were capable of, and to encourage the industry of the inhabitants.

To this brief account of some of the numerous productions of Mr. Wedgwood, we shall subjoin the tribute paid to his industry and genius by an elegant modern poet:

"Gnomes! as you now dissect with hammers fine
The granite rock, the noduled flint calcine;
Grind with strong arm, the circling chertz betwixt,
Your pure kaolins and petuntses mixt;
O'er each red saggar's burning cave preside,
The keen-eyed fire-nymphs blazing by your side;
And pleased on Wedgwood ray your partial smile,
A new Etruria decks Britannia's isle.
To call the pearly drops from Pity's eye;
Or stay Despair's disanimating sigh,
Whether, O Friend of Art! the gem you mould
Rich with new taste, with ancient virtue bold;
Form the poor fetter'd slave on bended knee
From Britain's sons imploring to be free;
Or with fair Hope the brightening scenes improve,
And cheer the dreary wastes of Sydney-cove;
Or bid Mortality rejoice and mourn
O'er the fine forms on Portland's mystic urn.
Whether, O Friend of Art! your gems derive
Fine forms from Greece, and fabled gods revive;
Or bid from modern life the portrait breathe,
And bind round Honour's brow the laurel wreath;
Buoyant shall sail, with Fame's historic page,
Each fair medallion o'er the wrecks of age;
Nor Time shall mar, nor Steel, nor Fire, nor Rust,
Touch the hard polish of the immortal bust."

The demand for Staffordshire ware very much increased, and it became a commercial article of exportation of very considerable value.

The district which Mr. Wedgwood inhabited became by his means the seat of population and abundance. The vicinity was enriched, and a new canal of importance, called the Grand Trunk canal, and connecting the Trent and the Mersey, was obtained and executed by his influence. The ample fortune which he acquired was liberally enjoyed, and benevolently applied to many purposes of private charity and public utility. Chemistry and the arts in their mutual connection were objects of his attention; and he contrived an instrument for measuring high degrees of heat, called a pyrometer, of which he gave an account in the Phil. Trans. for 1782, 1784, and 1786. See THERMOMETER.

The disposition and manners of Mr. Wedgwood were no less estimable than the powers of his mind; so that he was as much the object of admiration and esteem for his moral as for his intellectual qualities. So much was he respected, and so desirable was the continuance of his useful life, that he died, universally regretted, at his house in Staffordshire, to which he gave the name of Etruria, in January 1795, in the 65th year of his age. Aikin's Chem. Dict. Gent. Mag. Parkes's Chemical Catechism. Parkes's Essays.

Weld

WELD, or WOLD, *refeda luteola* of Linnæus, a plant ufed by the dyers to give a yellow colour; and for this reafon called, in Latin, *luteola*, of *luteus*, yellow. For the characters, fee RESEDA.

When the plants are pulled, they may be fet up in fmall handfuls to dry in the field, and when dry enough, tied up in bundles and houfed dry; care being taken to houfe them loofely, that the air may pafs between them to prevent their fermenting. That which is left for feeds fhould be pulled as foon as the feeds are ripe, and fet up to dry, and then beat out for ufe; for if the plants are left too long, the feeds will fcatter. Mortimer and Miller.

Weld is much cultivated in Kent, for the ufe of the London dyers.

Mr. Hellot obferves, in his Art de Teindre, that for dyeing with weld, the beft proportions of alum and tartar for the preparatory liquor are four parts of alum, and one of tartar, to fixteen of the wool; the quantity of the tartar being determined by the greater or lefs brightnefs of colour propofed; and that the wool, thus prepared, is to be boiled again with three or four parts of weld to one of wool, but often much lefs: that for light fhades, it is cuftomary to diminifh the alum, and omit the tartar; and that, in this cafe, the colour is more flowly imbibed, and proves lefs durable.

With a view to economy, the weaker fhades of colour are dyed in the fame bath, after the ftronger are finifhed. A golden yellow, more or lefs orange, is given by a weak madder bath, after the welding.

Silk is dyed of a golden-yellow, generally with weld alone, according to the following procefs: the ftuff is firft boiled in foap-water, alumed and wafhed, then paffed twice through a weld bath, in which, the fecond time, fome alkali is diffolved, which gives a rich golden hue to the natural yellow of the weld. The colour is further deepened by a little annotto. The folutions of lime with weld give to filk a bright clear yellow. In order to dye cotton yellow, Berthollet directs firft to cleanfe it with wood afhes and water, to rinfe, alum, and dry without further rinfing, and then to pafs it through a yellow bath, in which the weld is fomewhat more than the weight of the cotton. When the colour has fufficiently taken, the cotton is thrown into a bath of fulphate of copper and water, and kept there for an hour; after which it is boiled with white foap-water, and, laftly, wafhed and dried. In order to obtain a deeper jonquil-yellow, the aluming is omitted, and, inftead of this operation, a little verdigrife is added to the weld bath, and the cotton finifhed with foda.

Weld is particularly preferred to all other fubftances in giving the lively green lemon-yellow. It is, however, expenfive; and it is alfo found to degrade and interfere with madder colours more than other yellows. We may here add, that the fine delicate yellow, obtained from weld, is much ufed by the London paper-ftainers, and fold in the form of hard lumps, confifting chiefly of chalk faturated with the colouring matter. Meffrs. Collard and Frafer have given the following improved procefs:—Diffufe any quantity of fine whiting in boiling water; add to it one ounce of alum for every pound of whiting, which will occafion a brifk effervefcence, and ftir thefe materials well together till the gas is wholly difengaged. On the other hand, boil in a feparate veffel fome weld with water juft fufficient to cover it, for fifteen minutes, filter the yellow decoction, and then mix it with the whiting and alumine in fuch proportions, that the earths may appear to be faturated with the colouring matter. Then let the mixture remain a day at reft, and at the bottom will be the precipitated earth firmly united with the colour, and of a fine yellow tinge, which may be conveniently dried on chalk-ftones.

The weld yellow is a water colour, and is never mixed with oil.

Welding

WELDING, in the *Manufactures*, denotes the forging of iron, when intenſely heated; or, more generally, the intimate union which ſubſiſts between the two ſurfaces of two pieces of malleable metal, when heated almoſt to fuſion, and hammered. This union is ſo ſtrong, that when two bars of metal are properly welded, the place of junction is as ſtrong relatively to its thickneſs as any other part of the bar. Welding heat is the heat neceſſary for producing this effect. Bar-iron cannot be welded to another piece of iron, unleſs both be heated to nearly 60° of Wedgwood's pyrometer, which is equal to 8.877 of Fahrenheit's ſcale, and is called the welding heat; but if caſt-ſteel be heated to this point, it would be fuſed, and run from under the hammer; and, therefore, it was for a long time thought to be impoſſible to uſe it in conjunction with iron, in the ſame manner as the other kinds of ſteel are employed. But ſir Thomas Frankland at length diſcovered, that if the caſt-ſteel be made only of a white heat, and the iron of a welding heat, the ſteel will then be ſoft enough to unite with the iron, and yet the former will not become fluid by the operation. It will, however, be proper to give the neceſſary temperatures to the two metals ſeparately, and then to unite them at one ſingle heat. (Phil. Tranſ. for 1795, p. 296.) Mr. Parkes obſerves, that ſome nicety is required in the proceſs of welding iron, ſo that the outſide of the weld does not oxidize too much and fly off in ſcales, before the inſide is brought up to a welding heat. When, therefore, a ſkilful workman is about to weld two pieces of iron, he carefully obſerves the progreſs of the heat; and if one becomes too hot, he rolls it in ſand to preſerve it from the action of the atmoſphere; and when one piece acquires the neceſſary temperature before the other, he covers that with ſand, whilſt he is bringing the correſponding piece up to a ſufficient heat for its uniting properly with the former. Silex, when mixed with the oxyd of iron, forms a very fuſible compound, which covers the work under operation, and prevents a further oxidation of the metal. Iron and platina are capable of a firm union by welding. See ſir John Hall's Experiments, in vol. vi. of Edinb. Phil. Tranſ. p. 71. Parkes's Eſſays, vol. iv.

WELDING, the proper heat ſmiths give their iron in the forge, in order to double up the ſame, when wanted to weld a work in the doublings, ſo as to be in one piece thick enough for the purpoſe it is wanted for.

WELDING-*Heat* is the ſtrong heat, when the iron is propereſt to bind.

WHEEL, ROTA, in *Mechanics*, a ſimple machine, conſiſting of a round piece of wood, metal, or other matter, which revolves on an axis.

For an account of the *wheel* and *axle*, as a mechanical power, ſee AXIS *in Peritrochio*, and MECHANICAL *Powers*.

The wheel is one of the principal mechanic powers. It has place in moſt engines: in effect, it is of an aſſemblage of wheels that moſt of our chief engines are compoſed. Witneſs clocks, mills, &c.

Its form is various, according to the motion it is to have, and the uſe it is to anſwer. By this it is diſtinguiſhed into *ſimple* and *dented*.

WHEELS, *Simple*, are thoſe whoſe circumference and axis are uniform, and which are uſed ſingly, and not combined. Such are the wheels of carriages, which are to have a double motion; the one circular about their axis; the other rectilinear, by which they advance along the road, &c. which two motions they appear to have; though, in effect, they have but one: it being impoſſible the ſame thing ſhould move, or be agitated, two different ways at the ſame time.

This one is a ſpiral motion; as is eaſily ſeen, by fixing a piece of chalk on the face of a wheel, ſo as that it may draw a line on a wall, as the wheel moves. The line it here traces is a juſt ſpiral, and ſtill the more curve, as the chalk is fixed nearer the axis.

The fact, however, has been diſputed; and it has been alleged, that nothing is more eaſy than for any one, who will take the trouble to make the experiment, to prove its falſehood. Place the chalk on the face of the wheel, as directed, and you will find that, ſo far from its deſcribing a juſt ſpiral, and that ſtill the more curve as the chalk is fixed nearer the axis, the chalk, if placed on the periphery of the wheel, will deſcribe a cycloid, and the nearer it is placed to the axis, the nearer will the line it deſcribes approach to the ſtraight line which is deſcribed by the axis itſelf. Moreover, it is not true, nor pretended to be ſo, that the ſame thing moves two ways at once in the rectilinear and circular motion of wheels. The local motion, or motion of the whole wheel, is rectilinear only; that of the parts of the wheel circular. Nor can this latter motion with any propriety be called that of the wheel, unleſs the ſame thing could alſo move quick and ſlow at the ſame time, which the different parts of the wheel, in revolving round its axis, evidently do. Jacob's Obſ. on the Structure and Draught of Wheel-Carriages, 1773, p. 28, &c.

For a very nice phenomenon, in the motion of theſe wheels, ſee ROTA *Ariſtotelica*.

We ſhall add, that, in wheels of this kind, the height ſhould always be proportioned to the ſtature of the animal that draws or moves them. The rule is, that the load and the axis of the wheels be of the ſame height with the power that moves them; otherwiſe the axis being higher than the beaſt, part of the load will lie upon him; or, if it be lower, he pulls to diſadvantage, and muſt exert a greater force. Though Stevinus, Dr. Wallis, &c. ſhew, that, to draw a vehicle, &c. over waſte uneven places, it were beſt to fix the traces to the wheels ſomewhat lower than the horſe's breaſt. See WHEELS *of Coaches*, &c.

The power of theſe wheels reſults from the differences of the radii of the axis, and circumference. The canon is this: "As the radius of the axis is to that of the circumference, ſo is any power to the weight it can ſuſtain hereby."

This is alſo the rule in the axis in peritrochio; and, in effect, the wheel, and the axis in peritrochio, are the ſame thing; only, in theory, it is uſually called by the latter name, and in practice by the former.

WHEELS, *Dented*, are thoſe either whoſe circumference, or axis, is cut into teeth, by which they are capable of moving and acting on one another, and of being combined together.

The uſe of theſe is very conſpicuous in clocks, jacks, &c.

The power of the dented wheel depends on the ſame principle as that of the ſimple one. It is only that to the ſimple axis in peritrochio, which a compound lever is to a ſimple lever.

Its doctrine is comprifed in the following canon; *viz.* "The ratio of the power to the weight," in order for that to be equivalent to this, "muſt be compounded of the ratios of the diameter of the axis of the laſt wheel to the diameter of the firſt; and of the ratio of the number of revolutions of the laſt wheel, to thoſe of the firſt, in the ſame time." But this doctrine will deſerve a more particular explanation.

1. Then, if the weight be multipled into the product of the radii of the axes, and that product be divided by the product of the radii of the wheels, the power required to ſuſtain the weight will be found. Suppoſe, *e. gr.* the weight A (*Plate* XL. *fig.* 83. *Mechanics*,) = 6000 pounds, B C = 6 inches, C D = 34 inches, E F = 5 inches, E G = 35 inches, H I = 4 inches, H K = 27 inches: then will $BC \times EF \times HI = 120$; and $CD \times EG \times HK = 32130$. Hence the power required to ſuſtain the weight, will be $6000 \times 120 \div 32130 = 22\frac{1}{2}$ very nearly; a ſmall addition to which will raiſe it.

2. If the power be multiplied into the product of the radii of the wheels, and the factum be divided by the product of the radii of the axes; the quotient will be the weight which the power is able to ſuſtain. Thus, if the power be $22\frac{1}{2}$ pounds; the weight will be 6000 pounds.

3. A power and weight being given, to find the number of wheels, and in each wheel the ratio of the radius of the axis, to the radius of the wheel; ſo as that the power, being applied perpendicularly to the periphery of the laſt wheel, may ſuſtain the given weight.

Divide the weight by the power; reſolve the quotient into the factors which produce it. Then will the number of factors be the number of wheels; and the radii of the axes will be to the radii of the wheels, as unity to the ſeveral wheels. Suppoſe, *e. gr.* a weight of 3000 pounds, and a power of 60, the quotient of the former by the latter is 500, which reſolves into theſe factors, 4. 5. 5. 5. Four wheels are, therefore, to be made; in one of which, the radius of the axis is to the radius of the wheel, as 1 to 4; in the reſt, as 1 to 5.

4. If a power move a weight by means of two wheels, the revolutions of the ſlower wheel are to thoſe of the ſwifter, as the periphery of the ſwifter axis is to the periphery of the wheel that catches on it.

Hence, 1. The revolutions are as the radius of the axis F E to the radius of the wheel D C. 2. Since the num-

ber of teeth in the axis F D, is to the number of teeth in the circumference of the wheel M, as the circumference of that to the circumference of this; the revolutions of the flower wheel M, are to the revolutions of the fwifter N, as the number of teeth in the axis to the number of teeth in the wheel M, which it catches.

5. If the factum of the radii of the wheels G E, D C, be multiplied into the number of revolutions of the floweft wheel, M, and the product be divided by the factum of the radii of the axes which catch into them, G H, D E, &c. the quotient will be the number of revolutions of the fwifteft wheel O. *E. gr.* If G E = 8, D C = 12, G H = 4, D E = 3, and the revolution of the wheel M be 1; the number of revolutions of the wheel O will be 8.

6. If a power move a weight by means of divers wheels, the fpace paffed over by the weight, is to the fpace of the power, as the power to the weight. Hence, the greater the power, the quicker is the weight moved; and *vice verfâ.*

7. The fpaces paffed over by the weight and the power, are in a ratio compounded of the revolutions of the floweft wheel, to the revolution of the fwifteft; and of the periphery of the axis of that, to the periphery of this. Hence, fince the fpaces of the weight and the power are reciprocally as the fuftaining power is to the weight; the power that fuftains a weight will be to the weight, in a ratio compounded of the revolutions of the floweft wheel, to thofe of the fwifteft, and of the periphery of the axis of that, to the periphery of this.

8. The periphery of the axis of the floweft wheel, with the periphery of the fwifteft wheel, being given; as alfo the ratio of the revolutions of the one, to thofe of the other; to find the fpace which the power is to pafs over, while the weight goes any given length.

Multiply the periphery of the axis of the floweft wheel into the antecedent term of the ratio, and the periphery of the fwifteft wheel into the confequent term; and to thefe two products, and the given fpace of the weight, find a fourth proportional: this will be the fpace of the power. Suppofe, *e. gr.* the ratio of the revolutions of the floweft wheel, to thofe of the fwifteft, to be as 2 to 7, and the fpace of the weight 30 feet; and let the periphery of the axis of the floweft wheel be to that of the fwifteft, as 3 to 8: the fpace of the power will be found 280. For $2 \times 3 : 7 \times 8 :: 30 : 280$.

9. The ratio of the peripheries of the fwifteft wheel, and of the axis of the floweft; together with the ratio of their revolutions, and the weight, being given: to find the power able to fuftain it.

Multiply both the antecedents and the confequents, of the given ratios into each other, and to the product of the antecedents, the product of the confequents, and the given weight, find a fourth proportional: that will be the power required. Suppofe, *e. gr.* the ratio of the peripheries 8 : 3; that of the revolutions 7 : 2, and the weight 2000; the power will be found $214\frac{2}{7}$. For $7 \times 8 : 2 \times 3 :: 2000 : 214\frac{2}{7}$. After the fame manner may the weight be found; the power, and the ratio of the peripheries, &c. being given.

10. The revolutions the fwifteft wheel is to perform while the floweft makes one revolution, being given; together with the fpace the weight is to be raifed, and the periphery of the floweft wheel; to find the time that will be fpent in raifing it.

Say, As the periphery of the axis of the floweft wheel is to the given fpace of the weight; fo is the given number of revolutions of the fwifteft wheel to a fourth proportional: which will be the number of revolutions performed while the weight reaches the given height. Then, by experiment, determine the number of revolutions the fwifteft wheel performs in an hour; and, by this, divide the fourth proportional found before. The quotient will be the time fpent in raifing the weight. Wolf. Elem. Math. tom. ii. p. 214, &c.

WHEELS *of a Clock*, &c. are the crown wheel, contrate wheel, great wheel, fecond wheel, third wheel, ftriking wheel, detent wheel, &c. See CLOCK and WATCH.

WHEELS *of Coaches*, *Waggons*, &c. With refpect to thefe, the following particulars are collected from the experiments and reafonings of Camus, Defaguliers, Beighton, Fergufon, Brewfter, &c.

1. The ufe of wheels, in the draught of carriages, is two-fold; *viz.* that of diminifhing, or of more eafily overcoming the refiftance arifing from the friction of the carriage, and that of more readily furmounting obftacles, which form angular prominences on the plane over which they are drawn, and which muft be either depreffed by the weight of the carriage, or render it neceffary for the carriage, with its load, to be lifted over them. They ferve in their firft ufe to transfer the friction from the under furface of the carriage, and the plane fupporting it, to the furfaces of the axle and nave of the wheel. The common method of accounting for this advantage is by faying, that the refiftance, arifing from friction in planes of equal afperity, increafes with the velocity of the motion; fo that this velocity muft be compared with that of the power neceffary to move the machine, and overcome the friction; and it is obvious, at the fame time, that the velocity of a circular motion diminifhes gradually from the circumference to the centre. See FRICTION.

But to this pofition it has been objected, that the illuftration is not applicable to the cafe: for, granting that, in the friction of fledges or flat furfaces, the refiftance increafes in proportion to the velocity of their motion, this is not a parallel cafe with that of a circular furface rolling over a flat plane. On the contrary, the velocity of motion, in the outer furface of a wheel, is greater than that of its nave, moving under the axle; while at fuch outer furface there is little or no friction at all; whereas at the nave, moving much flower, there is much more. Indeed, the friction, which the wheel would have againft its fupporting plane, if it did not turn round its axis, is by its turning round transferred almoft wholly to the axis and nave; whofe circular motion is notwithftanding fo much flower. It is, indeed, notorious, that the great friction of the wheels of carriages lies between the axle and nave; and how then can it be properly afferted, that fuch friction is diminifhed at the axle, as the velocity of the circular motion is there diminifhed? Accordingly it has been alleged by a late writer, that friction is not diminifhed by the ufe of wheels, but merely transferred from the outer furface of the wheel to its nave and axle; and that in the cafe of a wheel rolling along the ground, the fpokes act only as fingle levers, to overcome the friction of the periphery againft the plane of its fupport, the prominences, conftituting the roughnefs of the plane over which it moves, being the fulcra upon which they turn, and not the common centre of thefe fpokes, as others have maintained, who fay that the wheel acts, in overcoming friction, as an axis in peritrochio. However, in obviating the friction of the wheels in loaded carriages, their fpokes act as double levers, refting on a fulcrum at each end. See the author's method of illuftrating and evincing thefe principles, in Jacob's Obf. on Wheel-Carriages, p. 23, &c.

If carriages were to move along fmooth horizontal planes,

wheels would be useful only in overcoming friction; but as they are drawn along roads covered with loose stones, indented with cavities, they are farther useful in serving to depress, or raise the carriage over the one, and in raising it out of the other.

2. The wheels of all carriages ought to be exactly round; and the fellies should be at right angles to the naves, according to the inclination of the spokes, *i. e.* the plane of the curvature of the wheel should cut the nave at right angles, though it need not pass through the place where the spokes are inserted into the nave.

3. The spokes, according to Mr. Ferguson and most other writers on mechanics, should be inclined to the naves, so that the wheels may be dishing or concave. If, indeed, the wheels were always to go upon smooth and level ground, it would be best to make the spokes perpendicular to the naves, or at right angles with the axles; because they would then bear the weight of the load perpendicularly, which is the strongest way for the wood. But because the ground is generally uneven, one wheel often falls into a cavity or rut, when the other does not, and then it bears much more of the weight than the other does; in which case dishing wheels are best, because the spokes become perpendicular in the rut, and therefore have the greatest strength when the obliquity of the road throws most of its weight upon them; whilst those on the high ground have less weight to bear, and therefore need not be at their full strength. Besides, by this form of the wheels, the base of the carriage is extended, and it is thus prevented from being easily overturned, and the fellies are hindered from rubbing against the load or the sides of the cart. Dr. Brewster, however, is of opinion, that the disadvantages of concave wheels overbalance their advantages. Mr. Anstice also, in his "Treatise on Wheel-Carriages," whilst he recommends concave wheels, candidly allows, that some disadvantages attend this construction of them; for the carriage thus takes up more room on the road, so that it is more unmanageable; and when it moves upon plane ground the spokes not only do not bear perpendicularly, by which means their strength is lessened, but the friction upon the nave and axle is made unequal, and so much the more as they are the more dished. Dr. Brewster farther shews, that they are more expensive, more injurious to the roads, more liable to be broken by accidents, and less durable in general, than those wheels in which the spokes are perpendicular to the naves. From these and other considerations, our author is decidedly of opinion, that if wheels are to be composed of naves, spokes, and fellies, the rim should be cylindrical, and the spokes perpendicular to the naves; whereas in concave wheels, the rims are uniformly made conical, which subjects them to a variety of disadvantages. Every cone that is put in motion upon a plane surface will revolve round its vertex, and if force is employed to confine it to a straight line, the smaller parts of the cone will be dragged along the ground, and the friction greatly increased. Now when a cart moves upon conical wheels, one part of the cone rolls while the other is dragged along, and though confined to a rectilineal direction by external force, their natural tendency to revolve round their vertex occasions a great and continued friction upon the linch-pin, the shoulder of the axle-tree, and the sides of deep ruts.

Dr. Brewster has made some farther observations on the construction of certain parts of the wheels. The iron plates, he says, of which the rims are composed, should never be less than three inches in breadth, as narrower rims sink deep into the ground, and therefore injure the roads and fatigue the horses. See the sequel of this article.

4. The axles of the wheels ought to be perfectly straight, and at right angles to the shafts, or to the pole. When the axles are straight, the rims of the wheels will be parallel to each other, and then they will move the easiest, because they will be at liberty to go on straight forwards. But in the usual way of practice, the axles are bent downwards at their ends; which brings the sides of the wheels next the ground nearer to one another than their higher sides are; and this not only makes the wheels to drag sideways as they go along, and gives the load a much greater power of crushing them than when they are parallel to each other, but also endangers the overturning of the carriage when any wheel falls into a hole or rut, or when the carriage goes on a road which has one side lower than the other, as along the side of a hill. Thus, in the hind view of a waggon or cart, let A E and B F (*Plate* XL. *fig.* 9. *Mechanics*) be the great wheels parallel to each other, on their straight axle K, and H C I the carriage loaded with heavy goods from C to G. Then as the carriage goes on in the oblique road A *a* B, the centre of gravity of the whole machine and load will be at C; and the line of direction C *d* D falling within the wheel B F, the carriage will not overset. But if the wheels be inclined to each other at the ground, as A E and B F are (*fig.* 10.), and the machine be loaded as before from C to G, the line of direction C *d* D falls without the wheel B F, and the whole machine tumbles over. When it is loaded with heavy goods which lie low, it may travel safely upon an oblique road, so long as the centre of gravity is at C (*fig.* 9.), and the line of direction C *d* D falls within the wheels; but if it be loaded high with lighter goods from C to L (*fig.* 11.), the centre of gravity is raised from C to K, which shews the line of direction K *k* without the lowest edge of the wheel B F, and then the load oversets the waggon. Mr. Beighton has offered several reasons to prove, that the axles of wheels ought not to be straight: for which we must refer to Desaguliers' Exp. Phil. vol. ii. Appendix, p. 540, &c. Moreover, if the axle were not at right angles to the pole or shaft, but this was on one side, then the coach or carriage would be drawn on one side, and almost all the weight would bear upon one horse. With some mechanics, it is a practice to bend the ends of the axle-trees forwards, and thus make the wheels wider behind than before. Mr. H. Beighton maintains, that wheels in this position are more favourable for turning; since, when the wheels are parallel, the outermost would press against the linch-pin, and the innermost would rub against the shoulder of the axle-tree. In rectilineal motions, however, these converging wheels occasion a great deal of friction, both on the axle and the ground, and must therefore be more disadvantageous than parallel ones. This fact is allowed by Mr. Beighton: but he seems to found his opinion upon this principle; that as the roads are seldom straight lines, the wheels should be more adapted to a curvilineal than to a rectilineal motion.

5. Large wheels are always more advantageous for rolling than small ones, in any case, or upon any ground whatever. If we consider wheels with regard to their friction upon the axles, it is evident, that small wheels must turn as much oftener round than the large ones, as their circumferences are less; and, therefore, a wheel which is twice as large as another will have twice the advantage in respect of the friction, the holes of the naves and axles, and the weights upon them, being equal. Again, if we consider the wheels as they sink into the earth, or fall into holes, the bearing of the great wheel being double that of the small one, it would sink but half so deep; and if the small wheel should meet with a hole of the same diameter with itself, it would wholly sink in, whilst only a segment less than half of the great

wheel would fall in: the ſame thing would alſo happen in marſhy ground, where the ſmall wheel would ſink wholly in the ſame hole which the great one would ſink into but in part. The large wheel would alſo have the advantage of a ſmall one in riſing over eminences or rubs that occurred; ſo that the former would go over rubs much higher than the latter; and indeed over any eminences, provided their height be not equal to its ſemidiameter. Deſaguliers has reduced this matter to a mathematical calculation, in his Exp. Phil. vol. i. p. 171, &c.

A late writer has alſo proved, that a wheel of eight feet diameter has ſomewhat more than twice the advantage in overcoming obſtacles of a wheel of two feet; and he found, in practice, that if it requires a certain power to draw a carriage of a certain weight over a certain obſtacle, with wheels of any determinate diameter, it will require wheels of four times that diameter, to draw the ſame carriage over the ſame obſtacle with half that power. This writer alſo obſerves, that, in the draught of carriages aſcending inclined planes, the moving power acts not only againſt the vis inertiæ, which is always equal to the abſolute gravity of the load, but alſo againſt its relative gravity, which increaſes with the inclination of the plane; and with reſpect to carriages raiſed on wheels, it is to be obſerved, that the higher the axle is removed from the plane, the farther is the centre of gravity removed out of the perpendicular line of ſupport; ſo that the lower the wheel, the leſs is the relative gravity of the carriage. Hence he infers, that ſuppoſing the friction of two carriages of equal weight, but of different ſized wheels, to be equal, the low-wheeled one would be drawn up hill, on a ſmooth plane, much more eaſily than the high-wheeled one; though on a ſmooth, horizontal plane, the latter would be drawn more eaſily than the former. On the contrary, in going down hill, the high-wheeled carriage will be urged forward, by its relative gravity, more than the low-wheeled one. Jacob, ubi ſupra, p. 63, &c.

It appears, therefore, that the larger wheels are, the more advantageous they are in proportion, provided that they are not more than five or ſix feet in diameter; for when they exceed theſe dimenſions, they become heavy; or if they are made light, their ſtrength is proportionably diminiſhed, and the ſpokes, being long, are more liable to break: beſides, horſes applied to ſuch wheels, would be incapable of exerting their utmoſt ſtrength, by having the axles higher than their breaſts, ſo that they would draw downwards; as in ſmall wheels the draught is made more difficult, by the horſes drawing upwards.

It is obſerved by Dr. Brewſter, in the appendix to his edition of "Ferguſon's Mechanics," that when the wheels of carriages either move upon a level ſurface, or overcome obſtacles which impede their progreſs, they act as mechanical powers, and may be reduced to levers of the firſt kind. In order to elucidate this remark, which is of great importance in the preſent diſcuſſion, let A be the centre, and B C N the circumference of a wheel 6 feet in diameter, and let the impelling power P, which is attached to the extremity of a rope A D P, paſſing over the pulley D, act in the horizontal direction A D. Then, if the wheel is not affected by friction, it will be put in motion upon the level ſurface M B, when the power P is infinitely ſmall. For ſince the whole weight of the wheel reſts on the ground at the point B, which is the fulcrum of the lever A B, the diſtance of the weight from the centre of motion will be nothing, and therefore the mechanical energy of the ſmalleſt power P, acting at the point A, with a length of lever A B, will be infinitely great when compared with the reſiſtance of the weight to be raiſed; and this will be the caſe, however ſmall the lever A B, and however great be the weight of the wheel. But as the wheels of carriages are conſtantly meeting with impediments, let C be an obſtacle ſix inches high, which the wheel is to ſurmount. Then the ſpoke A C will repreſent the lever, C its fulcrum, A D the direction of the power; and if the wheel weighs 100 pounds, we may repreſent it by a weight W, fixed to the wheel's centre A, or to the extremity of the lever C A, and acting in the perpendicular direction A B, in oppoſition to the power P. Now the mechanical energy of the weight W to pull the lever round its fulcrum in the direction A E, is repreſented by C E, while the mechanical energy of an equal weight P to pull it in the oppoſite direction A F, is repreſented by C F; an equilibrium, therefore, will be produced, if the power P is to the weight W as C E to C F, or as the ſine is to the coſine of an angle, whoſe verſed ſine is equal to the height of the obſtacle to be ſurmounted; for E B, the height of the mound C, is the verſed ſine of the angle B A C, and C E is the ſine, and C F the coſine of the ſame angle. In the preſent caſe, where E B is ſix inches, and A B three feet, E B, the verſed ſine, will be 1666, &c. when A B is 1000; and, conſequently, the angle B A C will be 33° 33′, and C E will be to E F, as 52 to 83, or as 66 to 100. A weight P, therefore, of 66 pounds, acting in a horizontal direction, will balance a wheel ſix feet diameter, and 100 pounds in weight, upon an obſtacle ſix inches high; and a ſmall additional power will enable it to ſurmount that obſtacle. But if the direction, A D, of the power, be inclined to the horizon, ſo that the point D may riſe towards H, the line F C, which repreſents the mechanical energy of P, will gradually increaſe, till D A has reached the poſition H A, perpendicular to A C, where its mechanical energy, which is now a maximum, is repreſented by A C, the radius of the wheel; and ſince E C is to C A as 53 to 1000, a little more than 53 pounds will be ſufficient for enabling the wheel to overcome the obſtacle.

Proceeding in this way, it will be found, ſays our author, that the power of wheels to ſurmount eminences increaſes with their diameter, and is directly proportional to it, when their weight remains the ſame, and when the direction of the power is perpendicular to the lever which acts againſt the obſtacle. Hence we ſee the great advantages which are to be derived from large wheels, and the diſadvantages which attend ſmall ones. There are ſome circumſtances, however, which confine us within certain limits in the uſe of large wheels. When the radius A B of the wheel is greater than D M, the height of the pulley, or of that part of the horſe to which the rope or pole D A is attached, the direction of the power, or the line of traction A D, will be oblique to the horizon as A *d*, and the mechanical energy of the power will be only A *e*, whereas it was repreſented by A E when the line of traction was in the horizontal line D A. Whenever the radius of the wheel, therefore, exceeds four feet and a half, the height of that part of the horſe to which the traces ſhould be attached, the line of traction A D will incline to the horizon, and by declining from the perpendicular A H, its mechanical effort will be diminiſhed; and ſince the load reſts upon an inclined plane, the trams or poles of the cart will rub againſt the flanks of the horſe, even in level roads, and ſtill more ſeverely in deſcending ground. Notwithſtanding this diminution of force, however, ariſing from the unavoidable obliquity of the impelling power, wheels exceeding four and a half feet radius have ſtill the advantage of ſmaller ones; but their power to overcome reſiſtances does not increaſe ſo faſt as before. Hitherto we have ſuppoſed the weight of the large and ſmall wheels to be the ſame, but

it is evident that when we augment their diameter we add greatly to their weight; and by thus increasing the load, we sensibly diminish their power.

From these remarks, we see the superiority of great wheels to small ones, and the particular circumstances which suggest the propriety of making the wheels of carriages less than four feet and a half radius. But even this size is too great; and it may be safely asserted that they should never exceed six feet in diameter, nor ever be less than three feet and a half.

6. Carriages with four wheels, as waggons or coaches, are much more advantageous than carriages with two wheels, as carts and chaises; for in applying horses to a carriage with two wheels, it is plain that the tiller carries part of the weight, in whatsoever manner it be kept in equilibrio upon the axle. In going down a hill, the weight bears upon the horse; and in going up a hill, the weight falls the other way, and lifts the horse, by which means part of his force is lost. Besides, as the wheels sink into the holes in the road, sometimes on one side, sometimes on the other, the shafts strike against the tiller's flanks, which is the destruction of many horses. Add to this, that when one of the wheels sinks into a hole or rut, half the weight will fall that way, whereby the carriage will be in danger of being overturned.

7. It would be much more advantageous to make the four wheels of a coach or waggon large, and nearly of a height, than to make the fore-wheels of only half the diameter of the hind-wheels, as is usual in many places. The fore-wheels of carriages have commonly been made of a less size than the hind ones, both on account of turning short, and to avoid cutting the braces. Crane-necks have also been invented for turning yet shorter, and the fore-wheels have been lowered, so as to go quite under the bend of the crane-neck. See an account of an ingenious contrivance for this purpose, under PERCH.

Some carriers and coachmen have, indeed, absurdly alleged, that when the fore-wheels are much lower than the hind ones, they serve to push them on. However, many disadvantages attend this construction. A considerable force is lost that would be effectual, if they were large: the carriage would go much more easily, if the fore-wheels were as high as the hind-ones; and the higher the better, because their motion would be so much the slower on their axles, and consequently the friction proportionably diminished. The jolting and uneasy motion occasioned by low wheels, has induced persons to contrive springs, in order to prevent it. But nothing can be more inconsistent, even with this end, than the common method of fixing the braces to the bottom of the body of a carriage. In consequence of this practice, the centre of gravity of the suspended body is so high above the centre of its motion, that it is liable to be continually agitated by the jolting of the carriage, and its danger of overturning increased: whereas if, instead of practising this method, the body were suspended as near as possible to its centre of gravity, the agitation of the carriage, as well as its danger of overturning, would be in a great measure avoided.

The effect of the suspension of a carriage on springs is to equalize its motion, by causing every change to be more gradually communicated to it, by means of the flexibility of the springs, and by consuming a certain portion of every sudden impulse in generating a degree of rotatory motion. This rotatory motion depends on the oblique position of the straps suspending the carriage, which prevents its swinging in a parallel direction; such a vibration as would take place if the straps were parallel, would be too extensive, unless they were very short, and then the motion would be somewhat rougher. The obliquity of the straps tends also in some measure to retain the carriage in a horizontal position; for if they were parallel, both being vertical, the lower one would have to support the greater portion of the weight, at least according to the common mode of fixing them to the bottom of the carriage; the spring, therefore, being flexible, it would be still further depressed. But when the straps are oblique, the upper one assumes always the more vertical position, and consequently bears more of the load; for when a body of any kind is supported by two oblique forces, their horizontal thrusts must be equal, otherwise the body would move laterally; and in order that the horizontal portions of the forces may be equal, the more inclined to the horizon must be the greater: the upper spring will, therefore, be a little depressed, and the carriage will remain more nearly horizontal than if the springs were parallel. The reason for dividing the springs into separate plates has already been explained: the beam of the carriage, that unites the wheels, supplies the strength necessary for forming the communication between the axles: if the body of the carriage itself were to perform this office, the springs would require to be so strong that they could have little or no effect in equalizing the motion, and we should have a waggon instead of a coach. The ease with which a carriage moves, depends not only on the elasticity of the springs, but also on the small degree of stability of the equilibrium, of which we may judge in some measure, by tracing the path which the centre of gravity must describe, when the carriage swings.

There is an inconvenience which attends the usual method of loading carriages; for when a carriage is loaded equally heavy on both axles, the fore-axle must endure as much more friction, and consequently wear out as much sooner than the hind-axle, as the fore-wheels are less than the hind ones. However, the carriers commonly put the heavier part of the load upon the fore-axle of the waggons; which not only makes the friction greatest where it ought to be least, but also presseth the fore-wheels deeper into the ground than the hind-wheels, although the fore-wheels, being less than the hind ones, are with so much the greater difficulty drawn out of a hole, or over an obstacle, even supposing the weights on their axles were equal; for the difficulty, with equal weights, will be as the depth of the hole, or height of the obstacle, is to the semi-diameter of the wheel. Moreover, since a small wheel will often sink to the bottom of a hole, in which a great wheel will go but a very little way, the small wheels ought to be loaded with less weight than the great ones; and then the heavier part of the load would be less jolted upward and downward, and the horses tired so much the less, as their draught raised their load to less heights. When the waggon-road, indeed, is much up-hill, there may be danger in loading the hind-part much heavier than the fore-part; for then the weight would over-hang the hind axle, especially if the load be high, and endanger tilting up the fore-wheels from the ground. In this case, the safest way would be to load it equally heavy on both axles; and then as much more of the weight would be thrown upon the hind axle than upon the fore one, as the ground rises from a level below the carriage. But as this seldom happens, a small temporary weight might be laid upon the pole between the horses, which would overbalance the danger.

From Mr. Ferguson's observations on the centre of gravity, it is evident, that if the axle-tree of a two-wheeled carriage passes through the centre of gravity of the load, the carriage will be in equilibrio in every position in which it can be placed with respect to the axle-tree; and

in going up and down hill, the whole load will be sustained by the wheels, and will have no tendency either to press the horse to the ground, or to raise him from it. But if the centre of gravity is far above the axle-tree, as it must necessarily be according to the present construction of wheel-carriages, a great part of the load will be thrown on the back of the horses from the wheels, when going down a steep road, and thus tend to accelerate the motion of the carriage, which the animal is striving to prevent: while in ascending steep roads a part of the load will be thrown behind the wheels, and tend to raise the horse from the ground, when there is the greatest necessity for some weight on his back, to enable him to fix his feet on the earth, and overcome the great resistance which is occasioned by the steepness of the road. On the contrary, if the centre of gravity is below the axle, the horse will be pressed to the ground in going up-hill, and lifted from it when going down. In all these cases, therefore, where the centre of gravity is either in the axle-tree, or directly above or below it, the horse will bear no part of the load in level ground. In some situations, the animal will be lifted from the ground when there is the greatest necessity for his being pressed to it, and he will sometimes bear a great proportion of the load when he should rather be relieved from it.

The only way of remedying these evils, says Dr. Brewster, is to assign such a position to the centre of gravity, that the horse may bear some portion of the load when he must exert great force against it, that is, in level ground, and when he is ascending steep roads; for no animal can pull with its greatest effort, unless it is pressed to the ground. Now, this may in some measure be effected in the following manner:—Let B C N (*Plate* XL. *fig.* 12.) be the wheel of a cart, A D one of the shafts, D that part of it where the cart is suspended on the back of the horse, and A the axle-tree; then if the centre of gravity of the load is placed at *m*, a point equidistant from the two wheels, but below the line D A, and before the axle-tree, the horse will bear a certain weight on level ground, a greater weight when he is going up-hill, and has more occasion for it, and a less weight when he is going down-hill, and does not require to be pressed to the ground. All this will be evident from the figure, when we recollect that if the shaft D A is horizontal, the centre of gravity will press more upon the point of suspension D the nearer it comes to it; or the pressure upon D, or the horse's back, will be proportional to the distance of the centre of gravity from A. If *m* therefore be the centre of gravity, *b* A will represent its pressure upon D, when the shaft D A is horizontal. When the cart is ascending a steep road, A H will be the position of the shaft, the centre of gravity will be raised to *a*, and *a* A will be the pressure upon D. But if the cart is going down hill, A C will be the position of the shaft, the centre of gravity will be depressed to *n*, and *c* A will represent the pressure upon the horse's back. The weight sustained by the horse, therefore, is properly regulated by placing the centre of gravity at *m*. We have still, however, to determine the proper length of *b a* and *b m*, the distance of the centre of gravity from the axle, and from the horizontal line D A; but as these depend upon the nature and inclination of the roads, upon the length of the shaft D A, which varies with the size of the horse, on the magnitude of the load, and on other variable circumstances, it would be impossible to fix their value. If the load, along with the cart, weighs four hundred pounds, if the distance D A be eight feet, and if the horse should bear fifty pounds of the weight, then *b* A ought to be one foot, which being one-eighth of D A, will make the pressure upon D exactly fifty pounds. If the road slopes four inches in one foot, *b m* must be four inches, or the angle *b* A *m* should be equal to the inclination of the road, for then the point *m* will rise to *a* when ascending such a road, and will press with its greatest force on the back of the horse.

When carts are not constructed in this manner, we may, in some degree, obtain the same end by judiciously disposing the load. Let us suppose that the centre of gravity is at O when the cart is loaded with homogeneous materials, such as sand, lime, &c. then if the load is to consist of heterogeneous substances, or bodies of different weight, we should place the heaviest at the bottom, and nearest the front, which will not only lower the point O, but will bring it forward, and nearer the proper position *m*. Part of the load, too, might be suspended below the fore-part of the carriage in dry weather, and the centre of gravity would approach still nearer the point *m*. When the point *m* is thus depressed, the weight on the horse is not only judiciously regulated, but the cart will be prevented from overturning, and in rugged roads the weight sustained by each wheel will be in a great degree equalized.

In loading four-wheeled carriages, great care should be taken not to throw much of the load upon the fore-wheels, as they would otherwise be forced deep into the ground, and require great force to pull them forward. In some modern carriages, this is very little attended to. The coachman's seat is sometimes enlarged so as to hold two persons, and all the baggage is generally placed in the front, directly above the wheels. By this means the greatest part of the load is upon the small wheels, and the draught becomes doubly severe for the poor animals, who must thus unnecessarily suffer for the ignorance and folly of man.

There is another great disadvantage attending small fore-wheels; *viz.* that as their axle is below the level of the horse's breasts, the horses not only have the loaded carriage to draw along, but also part of its weight to bear, which tires them sooner, and makes them grow much stiffer in their hams, than they would be if they drew on a level with the fore-axle; and for this reason, coach-horses soon become unfit for riding. So that on all accounts it is plain, that the fore-wheels of all carriages ought to be so high as to have their axles even with the breasts of the horses; which would not only give them a fair draught, but likewise cause the machine to be drawn by a less degree of power.

Mr. Beighton disputes the propriety of fixing the line of traction on a level with the breast of a horse, and says it is contrary to reason and experience. Horses, he says, have little or no power to draw, but what they have from their weight; otherwise they could take no hold of the ground, and then they must slip, and draw nothing. Common experience also teaches, that if a horse is to convey a certain weight, he ought, that he may draw the better, to have a proportional weight on his back or shoulders. Besides, when a horse draws hard, he bends forward, and brings his breast near the ground; and then, if the wheels are high, he is pulling the carriage against the ground. A horse tackled in a waggon will draw two or three ton, because the point or line of traction is below his breast, by reason of the wheels being low. And it is very common to see, when one horse is drawing a heavy load, his fore-feet will rise from the ground; and he will nearly stand on end; in which case it is usual to add a weight on his back, to keep his fore-part down, by a person mounting on him, which will enable him to draw that load, without which he before could not move. The great stress, or main business of drawing, says this ingenious writer, is to overcome obstacles; for on level plains the drawing is but little, and then the horse's back need be pressed but with a small weight. Most or all of these obstacles may be

confidered as inclined planes. In order to draw the wheel A B (*Plate* XL. *Mechanics*, *fig.* 13.) over the obftacle D, M. de Camus, agreeably to the principles above laid down, would have the horfe draw in the line H C; whereas Mr. Beighton fays, fince the obftacle is D, and the tangent of the earth, or line of the floor, is at B, and the line to be moved in is B D, an inclined plane; the eafieft pofition of drawing, to get the wheel over D, is to draw in the pofition of that inclined plane B T, or its parallel C *b*. As all the radii of a wheel are equal, the pulling at the centre is the fame as a balance in equilibrio; *viz.* there is the fame force at A as at B. But in the cafe of drawing in the horizontal line H C, when the obftacle is at D, the whole force which the horfe has for drawing is by the fhort end of the brachium $= e$ D, againft the force or weight of the long end of the brachium f D $= c$ C, which muft be very difadvantageous; therefore, he fays, the line of traction fhould be *b* C. Defag. Exp. Phil. vol. ii. App. p. 542, &c.

Whilft M. Camus maintained that the line of traction fhould be an horizontal line, or always parallel to the ground on which the carriage is moving, becaufe the horfe can exert his greateft ftrength in this direction, and becaufe the line of draught, being perpendicular to the vertical fpoke of the wheel, acts with the largeft poffible lever, M. Couplet, confidering that the roads are never perfectly level, and that the wheels are conftantly furmounting fmall eminences, even in the beft roads, recommends the line of traction to be oblique to the horizon. It is, however, to M. Deparcieux (Sur le Tirage des Chevaux, Mem. Acad. Roy., 1760.), that we are principally indebted for juft ideas on this fubject. He has fhewn in the moft fatisfactory manner that animals draw by their weight, and not by the force of their mufcles. In four-footed animals, the hinder feet are the fulcrum of the lever by which their weight acts againft the load; and when the animal pulls hard, it depreffes its cheft, and thus increafes the lever of its weight, and diminifhes the lever by which the load refifts its effects. Thus in *Plate* XL. *Mechanics*, *fig.* 12, let P be the load, D A the line of traction, and let us fuppofe F C to be the hinder leg of the horfe, A F part of its body, A its cheft or centre of gravity, and C E the level road. Then A F C will reprefent the crooked lever by which the horfe acts, which is equivalent to the ftraight one A C. But when the horfe's weight acts downwards at A, round C as a centre, fo as to drag forward the rope A D, and raife the load P, C E will reprefent the power of the lever in this pofition, or the lever of the horfe's weight, and C F the lever by which it is refifted by the load, or the lever of refiftance. Now, if the horfe lowers its centre of gravity A, which it always does when it pulls hard, it is evident that C E, the lever of its weight, will be increafed, while C F, the lever of its refiftance, will be diminifhed, for the line of traction A D will approach nearer to C E. Hence we may fee the great benefit which may be derived from large horfes, for the lever A C neceffarily increafes with their fize, and their power is always proportioned to the length of this lever, their weight remaining the fame. Large horfes, therefore, and other animals, will draw more than fmall ones, even though they have lefs mufcular force, and are unable to carry fuch a heavy burden. The force of the mufcles tends only to make the horfe carry continually forward his centre of gravity; or, in other words, the weight of the animal produces the draught, and the play and force of its mufcles ferve to continue it.

From thefe remarks, then, according to Dr. Brewfter's ftatement, we may deduce the proper pofition of the line of traction. When the line of traction is horizontal, as A D, the lever of refiftance is C F; but if this line is oblique to the horizon, as A *d*, the lever of refiftance is diminifhed to C *f*, while the lever of the horfe's weight remains the fame. Hence it appears, that inclined traces are much more advantageous than horizontal ones, as they uniformly diminifh the refiftance to be overcome. Deparcieux, however, has inveftigated experimentally the moft favourable angle of inclination, and found, that when the angle D A F, made by the trace A *d*, and a horizontal line, is fourteen or fifteen degrees, the horfes pulled with the greateft facility and force. This value of the angle of draught will require the height of the fpring-tree bar, to which the traces are attached in four-wheeled carriages, to be one-half of the height of that part of the horfe's breaft to that with which the fore end of the traces is connected.

This height is about four feet fix inches, and therefore the height of the fpring-tree bar fhould be only two feet three inches, whereas it is generally three feet.

8. The utility of broad wheels, in amending and preferving the roads, has been fo long and generally acknowledged, as to have occafioned feveral acts of the legiflature to enforce their ufe. See Turnpike.

Several excellent and well-devifed experiments have not long ago been inftituted by Boulard and Margueron, which have fatisfactorily evinced the diftinguifhing advantage of broad wheels. See a Memoir prefented to the Academy of Lyons, in the Journal de Phyfique, tom. xix. p. 424.

Neverthelefs, the proprietors and drivers of carriages feem to be convinced by experience, that a narrow-wheeled carriage is more eafily and fpeedily drawn by the fame number of horfes than a broad-wheeled one of the fame burthen. And though government allowed them to draw with more horfes, and carry greater loads than ufual, they were perfuaded with difficulty to comply with the requifition of legiflature; and methods have been ufed to evade it. Their principal objection has been, that as a broad wheel muft touch the ground in many more points than a narrow wheel, the friction muft of courfe be fo much the greater; not confidering, that if the whole weight of the waggon, and load in it, bears upon many points, each fuftains a proportionable lefs degree of weight and friction than when it bears only upon a few points; fo that what is wanting in one is made up in the other, and, therefore, will be juft equal under equal degrees of weight, as appears by the following plain and eafy experiment propofed by Mr. Ferguson.

Let one end of a piece of packthread be faftened to a brick, and the other end to a common fcale for holding weights; then having laid the brick edgeways on a table, and letting the fcale hang under the edge of the table, put as much weight into the fcale as will juft draw the brick along the table. Then taking the brick to its former place, lay it flat on the table, and leave it to be acted upon by the fame weight in the fcale as before, which will draw it along with the fame eafe as when it lay upon its edge. In the former cafe, the brick may be confidered as a narrow wheel on the ground; and in the latter as a broad wheel. And fince the brick is drawn along with equal eafe, whether its broad fide or narrow edge touches the table, it fhews that a broad wheel might be drawn along the ground with the fame eafe as a narrow one, fuppofing them equally heavy, even though they fhould drag, and not roll as they go along. Befides, as narrow wheels are always finking into the ground, efpecially when the heavieft part of the load lies upon them, they muft be confidered as conftantly going up hill, even on level ground; and their edges muft fuftain much friction by

rubbing againſt the ſides of the ruts made by them. But both theſe inconveniences are avoided by broad wheels; which, inſtead of cutting and ploughing up the roads, roll them ſmooth, and harden them: though, after all, it muſt be confeſſed, that they will not do in ſtiff, clayey croſs roads; becauſe they would ſoon gather up as much clay as would be almoſt equal to the weight of an ordinary load; and alſo in paſſing along roads abounding with looſe ſtones and other obſtacles, which a narrow wheel may avoid paſſing over, and a broad one muſt ſurmount, the broad-wheel carriage will certainly be drawn leſs eaſily and leſs ſpeedily than a narrow-wheeled one, though not on account of any additional friction ariſing from the preſſure of the weight on a greater quantity of ſurface. Broad wheels are likewiſe more liable to an inequality of preſſure between the axle and box than narrow ones, and conſequently to a greater wear and tear.

Jacob's Obſ. on the Structure and Draught of Wheel-Carriages, 1773, p. 81, &c. See on the ſubject of the preceding article, Deſag. Ex. Phil. vol. i. p. 201, &c. Ferguſon's Lect. p. 56, &c. 4to., and Appendix by Brewſter. Martin's Phil. Brit. vol. i. p. 229, &c.

We ſhall here ſubjoin ſome additional remarks on wheels and axles for carriages. The eſſential qualities of wheels are ſtrength and durability, and it is deſirable that they ſhould be as light as is conſiſtent with ſtrength: for quick travelling carriages lightneſs is very neceſſary.

Wheels to four-wheel carriages ſhould be made as near of a height as the conſtruction and appearance will admit; and if not required for heavy work, the lighter they are made the better. The fixtures from whence the draught is taken ſhould be placed rather above the centre of the largeſt wheel, for advantage of draught.

The members of a wheel are of three deſcriptions; *viz.* the nave, or ſtock, which is the central piece; the ſpokes, or radii; and the fellies, or circumference. The nave or ſtock is made of elm, in which all the ſpokes are fixed, and in which the axletree-box, or wheel-box, is confined, to receive the axle-arms on which the wheel revolves. The ſpokes are ſtraight timbers made of oak, firmly tenoned in the nave, in the direction of radials, to ſupport the fellies, or wheel-rim. The fellies are made of aſh, or beech, and form the rim of the wheel; the whole circumference is uſually divided into ſhort lengths, in the proportion of one length to every two ſpokes. When the fellies are fixed on the ſpokes, the iron band, or tire, which maintains the wear, is nailed on in lengths, and keeps the fellies together. The diameters of wheels regulate the number of ſpokes and fellies they are to contain: for the larger the circumference of the wheel is, the greater is the number of ſpokes required in proportion; for they ſhould not in any wheel be more than fifteen inches diſtant on the fellies, or circumference.

The uſual height or diameter of wheels for coaches and travelling carriages extends to five feet eight inches, and are divided into four proportions. Thoſe which contain from eight to fourteen ſpokes, and only half that number of fellies, are called eights, tens, twelves, or fourteens, which are the number of ſpokes in ſuch wheels, or of fellies in a pair of wheels. The height which regulates the number is, for an eight-ſpoke wheel, not to exceed three feet two inches; for a ten, four feet ſix inches; for a twelve, five feet four inches; for a fourteen, five feet eight inches.

Theſe are the extreme heights for the different numbers of ſpokes to each wheel, which ſhould be rather more than leſs, in particular for the fore-wheel of a four-wheel carriage, which receives more ſtreſs than the hind one; and the coach-maker's rule is, when the hind-wheels are of that height to require fourteen ſpokes, the fore one, if under the neceſſary height before ſtated, ſhould have twelve; never allowing the fore-wheels to have but two ſpokes leſs than what is needful for the hind ones.

There are three deſcriptions of wheels; *viz.* the ſtraked, the hooped, and the patent rim: the differences of theſe are only in the rims.

The ſtraked wheel is made with the fellies in ſeparate lengths or pieces, which are joined together at the ends by dowels; that is, a round pin which enters part into one piece and part into the other, being cloſely fitted into holes made in each. The iron with which it is plated is called the ſtrake, and is put on in pieces of the ſame length as the pieces of the fellies, and faſtened by nails; the joints of the iron are made to fall over the middle of the pieces of wood ſo as to unite them firmly together. The hooped wheel is ſurrounded by a hoop of iron in one entire piece. The patent wheel is made with a hoop of wood in one entire piece, by boiling or ſoftening the wood until it can be bent into a circle; this is ſurrounded by a hoop of iron in an entire piece, and faſtened by nuts and rivets.

According to the uſual method of conſtructing ſtraked wheels, their peripheries are compoſed of a number of pieces or fellies joined together; but theſe are weak, and ſubject to ſeveral inconveniences. As the joints are the weakeſt parts of the wheel, they are moſt liable to yield inward; for which reaſon the wheelwrights leave them higher than the other parts of the rim, in conſequence of which the wheel is not exactly round withinſide the circle of the rim. Beſides, the fellies being ſegments of a circle, ſawed or hewn out of ſtraight wood, they are on this account rendered ſo brittle, from the croſs direction of the grain near the joints, that they are with difficulty kept together, even though almoſt twice the quantity of timber be employed that would otherwiſe be neceſſary. The ſtrength of ſuch a wheel depends on the thickneſs of the iron tire or rim that ſurrounds it, and hence the carriage is loaded with an uſeleſs weight, both of wood and iron. To obviate theſe inconveniences, Mr. Viny invented the proceſs for bending timber into a circular form, practiſed for ſome time by Meſſrs. Jacob and Viny, and is now continued by others. In wheels made of timber thus bent, the rim conſiſts either of a ſingle piece of wood, or two fellies only, and is caſed with a ſingle hoop of iron. By this mode of conſtruction, the grain of the wood is kept parallel throughout, ſo that the periphery of the wheel is every where equally ſtrong; its thickneſs is conſiderably leſſened, inſomuch that though little more than half the uſual quantity of timber is employed, the wheel is of itſelf ſtrong enough to ſuſtain the common burthen laid on ſuch wheels, without the aſſiſtance of iron tires, which are only applied to them as a ſafe-guard, to preſerve the wood from the injuries to which it would otherwiſe be neceſſarily expoſed from the roads; and hence a leſs quantity of iron is ſufficient, and even that will be fairly worn out before it becomes uſeleſs. Beſides, the wheel is rendered much lighter, and at the ſame time much ſtronger and more durable, than wheels conſtructed of detached pieces of wood and iron, in the uſual manner. Theſe patent wheels are very ſuperior to the common ſort, in their neat light appearance, and in the length of time they wear, as two ſets of the former will wear as long as three of the latter: their preſervation depends very much on the hoops that the wheels are rimmed with. Some perſons ſtill prefer the common ſort of wheels, on account of their being more eaſily repaired than the hoop-wheel; but though the repairing of the latter is more difficult, they are much leſs ſubject to need it.

As the rims of wheels wear ſooneſt at their edges, they

ſhould be made thinner in the middle, and faſtened to the fellies with nails of ſuch a kind, that their heads may not riſe above the ſurface of the rim. The fellies on which the rims are fixed ſhould, in carriages, be three inches and a quarter deep, and in waggons four inches. The naves ſhould be thickeſt at the place where the ſpokes are inſerted, and the holes in which the ſpokes are placed ſhould not be bored quite through, as the greaſe upon the axle-tree would inſinuate itſelf between the ſpoke and the nave, and prevent that cloſe adheſion which is neceſſary to the ſtrength of the wheel.

The track in which the wheels of every carriage are to run is generally the ſame, except when intended for particular roads, where waggons and other heavy carriages are principally uſed, and leave very deep ruts, in which light carriages muſt likewiſe run, or be liable to accident, and are alſo ſure to be heavy in draught. All four-wheel carriages ſhould have the hind and fore wheels regulated to roll in the ſame track. The ordinary width of the wheels is four feet eight or ten inches; that of waggons or carts generally meaſure five feet two inches; chaiſe-wheels, as being principally intended for the country, are adapted to this width. It is immaterial to what width wheels are ſet if uſed for running upon ſtones; but on marſhy roads, if their exactneſs is not attended to, the draught is conſiderably increaſed. We have ſeen a carriage of which the iron axle-tree is made in two pieces, overlapping each other in the middle where they are joined, and ſecured by proper bands to the wood-work of the carriage, ſo as to admit of ſliding in the direction of the axle-tree. Theſe parts are cut with teeth like racks, and a pinion is applied between them; ſo that by turning this pinion round, the two parts of the axle-tree are made to ſlide one upon the other; and the wheels which are fitted upon the two extreme ends of the axle-tree can at pleaſure be fixed at greater or leſs diſtance, as the roads require.

The different heights of hind and fore wheels make alſo a difference in the length of their axle-trees, agreeable to the proportion they bear to one another; the fore-wheel has the longeſt axle-tree by one or two inches between the ſhoulders.

The nave of the wheel is pierced through the centre, with a large hole to introduce the box, or iron tube, for the axle-arm, as this tends to weaken the wood. It has been frequently propoſed to make metal naves, or centre-pieces for wheels, which ſhould contain the box for the axis, and the mortiſes for the ſpokes of the wheel all caſt of one piece of metal. Meſſrs. Dodſon and Skidmore had a patent for this in 1799. The objection to it is, that, if the wood of the ſpokes ſhrinks, they become looſe in the mortiſes, whereas a wooden nave ſhrinks at the ſame time with the ſpoke. This defect has been ſince remedied by making the metal wheel-ſtock in two parts; one with receſſes, or ſockets, to contain the ſpokes, and the other a flat plate to faſten againſt the former with ſcrew-bolts, and preſs the ſpokes into their cavities. Mr. Plucknet had a patent for a metal wheel-ſtock of this kind in 1805, which anſwered extremely well for carts, waggons, and artillery. The ſpokes were made to fill up all the ſpace in the nave or ſtock, ſo that each ſpoke touched its neighbour. The metal ſtock was only a flat circular plate, or flanch, projecting from the box which received the axle, and another flat plate fitted upon it, and bound againſt the former by ſcrew-bolts, one paſſing through each arm; theſe rendered the wheel very ſtrong.

Mr. Wilks took a patent in 1813 for a metal ſtock, in which there are complete cells for each ſpoke, and the cells are dove-tailed; that is, they are made larger at the central part than at the outſide, to prevent them from drawing out, and they are firmly preſſed into the dove-tails by the ſcrew-bolts which confine the moveable plate.

Wheels for railway-waggons are made of caſt-iron, and uſually all in one piece; but this is objectionable, becauſe the unequal contraction of the arms and rim of the wheel in cooling, after the wheel is caſt, puts the different parts on a ſtrain, and they frequently break without any adequate force. It is better to caſt the rim in one piece and the arms in another, and put them together with ſcrew-bolts, or rivets. Mr. Hawks had a patent for this in 1807. In this way, the rims may be replaced when worn out.

The Axle-trees for Wheels of Carriages.—The ſtrong iron bar which extends acroſs beneath the wood-work of the carriage, is called the axle-tree; the round parts at each end, on which the wheels run, are called the axle-arms; and the part or ſtem between them, which is fixed beneath the wood-work of the carriage, is alſo called the axle-tree. In the form of the latter parts there are but two ſorts, the one made flat, and called a bedded axle-tree, it being ſunk all its length in the under ſide of the timbers of the carriage; the other is made of an octagon form, and flat only at the ends where they are bedded.

The axle-arms on which the wheels turn ſhould be made perfectly round, and ſomewhat ſtronger at the ſhoulder than at the extreme end, which is ſcrewed to receive a nut, through which and the axle-tree the linch-pin paſſes, to keep all tight. The nuts are made with a collar at the face; and a temporary collar, or waſher, is driven on the back of the arms, which form two ſhoulders for the wheel to wear againſt, and helps to preſerve the greaſe from running out, and to prevent dirt from getting in.

As the axle-trees are the principal or only ſupport of the carriage, every attention and care ſhould be fixed in the ſelection of good iron; and to ſee that they be well wrought, and of ſufficient ſtrength, rather going to the extreme of ſtrength, than riſking the life of the paſſenger by the overſetting of the carriage, which moſtly happens when an axle-tree breaks.

By the bend of the axle-trees, the wheels are regulated to any width at bottom, to ſuit the track of the roads in which they are to run, and are confined in the carriage by means of clips, hoops, and bolts. The ſhape of the axle-tree between the ſhoulders varies according to the ſituation they are placed in, or the form of the timber of the carriage with which they are united; thoſe are the moſt firm that are flat, bedded in the timber. Axle-tree boxes for wheels are of various kinds; thoſe which are frequently called long-pipe, or wheel-boxes, are long tubes fitted accurately to the arms of the axle-trees, and ſecurely fixed in the wheel-ſtocks, or naves; they are uſually made of wrought ſheet-iron of a ſubſtance proportioned to the weight of the carriage; their uſe is to contain a ſupply of greaſe, and to prevent the effects of friction, whereby the wheels are much aſſiſted in their motion. Theſe are now uſed inſtead of the old caſt-iron boxes, which for quick travelling-carriages are totally out of uſe, being found injurious to the axle-trees, by cutting them at thoſe parts they wear againſt, ſo as to occaſion a frequent lining of the arms; but with the wrought metal boxes this is ſeldom neceſſary.

There are many ſorts of axle-trees and boxes invented various ways, with a view of attaining the following advantages; *viz.* To contain a longer ſupply of greaſe or oil, to be more durable, to ſecure the wheels, and to leſſen the draught. Thoſe are all certainly great advantages, and though the expence is great, the utility of either of them muſt be more than adequate to it, and merits more general notice.

Some of thefe inventors even pretend that all thefe advantages are combined in one axle-tree; but the generality extend to the advantage only of retaining a fupply of oil, and remaining perfect to a confiderable length of time. The common fort of axle-tree and box, which is moft generally ufed, is fimple and cheap in comparifon with the others.

Common Axle-tree.—The arms of the axle-tree are made round, but rather of a conical form, ftrongeft at the back or fhoulders, tapering to the linch end, which is fcrewed for a nut, and alfo has a fmall hole for a linch-pin, which prevents the nut from coming off: at the body-end is a wafher or collar for the back of the wheel-ftock to wear againft. The box is made of fheet-iron, proportioned in fubftance to the weight or fize of the axle-tree, having the edges of the plate, of which it is formed, welded in a ridge which projects on the outfide; this fecures the box in the nave of the wheel, and prevents it turning round therein.

The nut which fcrews on the end of the axle-arm has a broad face to lie flat againft the wheel, and is tapped or fcrewed to receive the fcrew-end of the axle-tree. Each of thofe nuts muft turn on the fcrew the fame way the wheel goes, and muft have a notch for the linch-pin to pafs through, for the purpofe of fecuring the nut from turning off.

The box is what, of the axle-tree, wears moft, and is frequently obliged to be refitted to the arms; otherwife they give to the wheel while in ufe an unfteady motion, and foon exhauft their ftock of greafe.

Thofe that are well fitted will contain their fupply for about one week with regular ufe, or a journey of one hundred miles. They wear at the rate of one fet of boxes to every two fets of wheels, and require in that time to be twice or thrice taken out of the wheels and refitted to the axle-tree arms.

Axle-trees with Friction-Wheels.—Thefe were invented by Mr. Garnet, at leaft the beft kind, which are made in a very ingenious manner. The wheel-box is made much larger than the axle-tree, in fuch manner that the fpace all round between them may receive a number of rollers which fill it up. (See a defcription in the article MILL-*Work.*) Mr. Garnet had a patent in 1784, and for fome years manufactured great numbers; but being very expenfive, they fell into difufe, although very complete. This invention has been lately revived by Mr. Panter.

The Patent Anti-Attrition Axle-tree and Box.—The propofed advantages of this axle-tree are, eafe of draft by diminution of friction; the retention of oil to fupply a month's ufe; the eafe with which it is replenifhed without taking off the wheels; the great fecurity for the wheels, which it prevents from coming off, and the carriage from overturning, if even the arm of the axle-tree fhould break; and their durability, and even improvement by wear. Thofe axle-trees, if made with the fecuring-collar, for the wheels need no nut or linch-pin, as is generally ufed, but the wheel may be taken off and put on as eafily as thofe on the common principle.

Thefe axle-arms are reduced at the bottom from a perfect round, and grooved, to receive two fmall rollers, on which the weight of the carriage is borne, and which greatly facilitates the motion, in the fame manner as blocks of ftone or timber, which require to be removed by the affiftance of rollers. Thefe rollers form the outer circumference of the axle-trees at bottom, which are reduced to give a bearing only on them. A circular box or ciftern is provided to contain a fupply of oil; it is clofely fitted to the back of the inner end of the wheel-ftock, and fixed by three bolts. The oil is here contained within three circular receffes, and oozes through fmall channels on the arm of the axle-tree, which it feeds for a confiderable time. This oil-box is made of caft-metal, and has a cap projecting behind over the axle-tree, which prevents the dirt from getting into the box. This axle-tree is alfo provided with what is called the wheel-fecurity, or ftrap-wafher. It is an iron collar, fitted on the external part of the wheel-ftock, and confined between the refervoir and ftock, lying as it were in a groove, fo that the collar cannot come off. This collar has two lugs or ftraps extending backwards fome diftance along that part of the axle-tree which is bedded in the wood-work, where it is fixed by a nut-fcrew. By means of this ftrap-wafher, the wheel is fecured to the bedded part of the axle-tree; and fhould the axle-arm within the wheel break, the wheel will continue to act.

The cap of this axle-tree is alfo fixed on the outfide part of the wheel-ftocks; by the fame three bolts which faften the oil-box, and by means of a fcrew-plug in the cap, the axle-tree and refervoir are replenifhed with oil. The box is of the fame form as the common box, only made of a very hard durable metal, of a confiderable thicknefs, and is made in proportion to the weight of the carriage.

Collinge's Patent Cylinder Axle-tree and Box.—Thefe axle-trees have been a confiderable time in ufe, and their advantages have been proved in the length of time they wear, in the filent and fteady motion they preferve to the wheels, in the advantage of retaining the oil to profecute a journey of two thoufand miles without being once replenifhed; and laftly, they are very durable, and but little fubject to be out of order.

The axle-tree arm is made as perfectly cylindrical as poffible, and of a peculiar hard fubftance; the middle of the cylinder is reduced, to contain the oil neceffary to feed the axle-trees; fo that the two bearings are at the two ends of the axle, which has an internal fhoulder, againft which the inner end of the wheel-box takes its bearings. Behind this fhoulder is a deep groove for a wafher to preferve the oil, and prevent noife in its ufe; alfo a rim, or hollow box, on the collar of the axle-tree, which overlaps part of the inner end of the wheel-ftock to keep out dirt, and anfwer the ufe of a cuttoo. The extreme end of the arm is double-fcrewed, to receive two nuts for fecuring the wheel: the one fcrew turns the way of the wheel; the other the reverfe, and is meant as an additional fecurity.

The box is made of a very hard metal, nicely polifhed, and fitted to the arms, having a circular recefs all round at the end neareft the carriage, for containing there a fupply of oil. The box is longer than the part which bears on the axle; and the projecting part beyond the bearing at each end is bored out larger than the arm. The back projection fits clofe to the rim of the collar, which it covers: the fore one projects outwards beyond the furface of the wheel-ftock, and is fcrewed on the infide to receive the fcrew of the cap.

There are many other patents for axle-trees to wheels; but as few of them have come into ufe, we fhall only notice Meffrs. Flight and Brook's patent axles. The axle is fixed faft to the nave of the wheel, by paffing through it. This axle turns round within the wheel-box; whereas in others the wheel-box turns round upon the axle.

The axle is cylindrical, and is received into a cylindrical box or tube in the end of the iron axle-tree, which is firmly bolted to the underfide of the timber of the carriage. To hold the axle in its place, and prevent it from drawing out of the box, the end of the axle is reduced to a knob or button, which adheres to the end of the axle by a fmall

neck. This button is fitted and received into a ſocket, in which it can freely turn round, but cannot draw out endways. It is made in a piece of metal, which is cylindrical on the outſide, and of the ſame ſize as the axle. It is made in two halves, which ſeparate longitudinally to introduce or take out the button at the end of the axle; but when the two halves are put together, the ſocket-piece forms as it were a continuation of the axle. When the axle is put into the box with this ſocket-piece at the end of it, the two halves of the ſocket will be confined together, ſo that they cannot ſeparate; and to prevent them from drawing out of the box, a ſcrew-bolt is put through the box, and paſſes through both halves of the ſocket: this holds the ſocket and the axle in their places.

Mr. Ackermann has recently obtained a patent (1818) for a valuable improvement in the application of the fore-wheels to four-wheeled carriages. In our article COACH-*Making*, vol. viii. we have deſcribed thoſe methods which were then known of applying the fore-wheels, ſo as to make a four-wheel carriage turn with ſafety, and in a ſmall ſpace. See alſo PERCH.

Mr. Ackermann's improvement effects this in the moſt perfect manner. Each of the fore axle-trees is connected with the carriage by means of a vertical axle, formed in the ſame piece with the horizontal axle, and upon which the wheel turns, the two axles being ſituated at right angles to each other. Theſe vertical axles are fitted into ſockets, formed at the two extremities of a croſs beam of the frame of the carriage, which is called the fore-ſpring tranſom. Upon theſe axles, as centres of motion, the axle-arms and wheels can be turned about horizontally, in order to place them obliquely to the direction of the hinder-wheels when the carriage is required to turn; but each axle turns upon a ſeparate centre of motion, and theſe centres are very near to their reſpective wheels, being at the extremities of the croſs-beam or tranſom; hence the fore-wheels do not change their place upon the ground when they are placed obliquely.

In a common carriage, the axles of the two fore-wheels are both fixed to one piece of timber, called the axle-bed, which is placed beneath the fore-tranſom, and united to it by a vertical pin called the perch-bolt, paſſing through the middle of the axle-bed. On this pin, as a centre, the axle-bed is turned round. When the wheels are to be placed obliquely, it is evident, that, in ſo turning upon a ſingle centre, one wheel muſt advance forwards, and the other muſt retreat backwards, ſo as to diminiſh the bearing of the carriage-wheels on the ground in a lateral direction, and at the ſame time the horſes are pulling in that direction which tends to overturn the carriage. Another inconvenience is, that one of the wheels will touch the perch of the carriage, if placed very oblique.

In the new improvement, two ſeparate centres of motion being uſed, and theſe being removed from each other as far as poſſible, many deſirable properties are attained.

To give the oblique direction to the wheels, each vertical axle has a lever proceeding backwards from it; and theſe two levers are united together by a connecting-bar, which obliges both axles to move at the ſame time with a ſympathetic action. The pole of the carriage is united to the piece, called the futchel, in the uſual manner; and the futchel is united to the ſpring-tranſom by a perch-bolt, in the uſual poſition; alſo the hinder end of the futchel is jointed to the middle of the connecting-bar, between the two levers of the vertical axles. The connecting-bar likewiſe anſwers the purpoſe of a ſway-bar.

When the horſes move to one ſide, the pole and futchel turn upon the perch-bolt, as a lever upon a centre of motion; and the extreme end of the futchel acts upon both vertical axles at once by means of the connecting-bar, ſo as to place both of the fore-wheels in an oblique direction. This is the invention of M. Lankenſperger of Munich.

WHEEL, *Ariſtotle's*. See ROTA *Ariſtotelica*.

WHEEL, *Blowing*, a machine contrived by Dr. Deſaguliers for drawing out the foul air of any place, or for forcing in freſh, or doing both ſucceſſively, without opening doors or windows. See Phil. Tranſ. N° 437.

The intention of this machine is the ſame as that of Dr. Hales's ventilator, but not ſo effectual, nor ſo convenient. See Deſagul. Courſe of Exper. Philoſ. vol. ii. p. 563. 568.

This wheel is alſo called a *centrifugal wheel*, becauſe it drives the air with a centrifugal force.

WHEELS, *Buſhes or Boxes of*, the inſide metal linings of the naves. See WHEEL.

WHEEL, *Cutting Roller*, in *Agriculture*, a tool of the cutting and reducing ſort, uſed for the purpoſe of working over crops in ſome caſes. In Oxfordſhire a cutting roller of this ſort has been invented, which is compoſed of twelve wheels, two inches and a half in thickneſs; and between each of them is a ſpace of two inches and a half. They are three feet in diameter. It is a load in working ſo as to be ſufficient exertion for a ſtrong team to draw it: it is paſſed over wheat after it has been ſown, or after it is come up; and if dry, croſs and croſs. It has alſo been uſed in the ſpring upon wheat; it leaves the ſurface rough in a ſort of diamond forms, which is found very beneficial in ſome of the wheat-lands of that diſtrict. It is alſo capable of being uſed in breaking down the ſurface of ſtiff tillage-land in many other caſes and circumſtances.

WHEEL, *Draining*, a wheel conſtructed for the purpoſe of cutting or making drains. Wheels differently formed are uſed for this ſort of work. In Eſſex they employ workmen who make uſe of a caſt-iron wheel which weighs about four hundred weight, and which is four feet in diameter; the cutting edge or extreme circumference of the wheel being half an inch in thickneſs, which increaſes in this way as it approaches towards the nave or centre; and will, at fifteen inches deep, ſcour out or cut a drain half an inch wide at the bottom, and four inches wide at the top. The wheel is ſo placed in a frame, that it may be loaded at pleaſure, and be made to paſs to a greater or leſs depth, as the nature of the land may be.

The writer of the Middleſex Report on Agriculture adviſes the uſe of a common ſix-inch cart-wheel, on the felly of which, all round, a ſort of ridge-formed addition of wood is to be fixed, and a rim of iron of a triangular ſhape faſtened to the wood. A wheel of this kind put on the axle of a cart, in the uſual way, will, of courſe, reſt on the edge of the rim of iron; and which, on driving the horſe forward, will make a ſmall indent or depreſſion in the ground merely by the revolution of it; but in order to make it preſs down to the depth of ſix or eight inches, that ſide of the cart ſhould be loaded with ſtones, iron ballaſt, or any other heavy material that may happen to be at hand, until the whole of the parts, if neceſſary, ſink into the ſoil. It would however be as well, or better, it is ſaid, if the rim parts added to the wheel were in one piece of caſt-iron; as the increaſed weight of it would enable it to cut or ſink without the aid of ballaſt, or with leſs than uſual. The cart ſhould then be drawn along in ſuch a manner, that the cutting or depreſſing wheel may revolve where the drains are intended to be made. In land that is in ridges and furrows, it will ſometimes be neceſſary to draw the wheel along every

furrow. When the ground is without ridge and furrow, the wheel ſhould be drawn over it in parallel lines, five or ten yards diſtant from each other. The wheel on the other end of the axle is a common ſix-inch wheel, ſupporting only the empty ſide of the cart, conſequently will not cut or depreſs the ground.

The advantage of this contrivance is, that it makes an indent or depreſſion in the ſurface ſoil of ſoft wet clayey graſs-lands, ſufficient to carry off the water during the ſame winter, by preſſing down the ſward and herbage without deſtroying it. In the following ſpring, theſe drains will be nearly grown up, and clothed with graſs; conſequently, there will be nothing taken from the paſturage or the ſcythe. It is neceſſary to obſerve, that the wheel muſt be drawn over the ground every year on the approach of winter. With it, and two old horſes, a ſtout boy or man may, it is ſaid, drain from ten to twenty acres in eight hours.

It may be found very uſeful in the graſs and hay land diſtricts about the metropolis and other places. See SURFACE *Draining*.

WHEEL, *Meaſuring*. See PERAMBULATOR.

WHEEL, *Orffyreus's*. See ORFFYREUS.

WHEEL, *Perſian*. See PERSIAN.

WHEEL-*Ploughs*, in *Agriculture*, all ſuch ploughs as are conſtructed with wheels. See PLOUGH.

WHEEL, *Potter's*, is a round board attached to a lathe, and capable of being moved by it, either rapidly or more ſlowly, as occaſion may require. This round board moves in a horizontal poſition; and when in uſe, the clay which is to be faſhioned is fixed on the centre of it; and it is put in motion either by a perſon who conſtantly attends it when at work, or by means of a treadle which is moved by the foot of the workman himſelf.

As the clay revolves upon this machine, the workman either models it by his fingers, or forms it, by means of an inſtrument which he holds in his hand, into any kind of circular ſhape that he may deſire; and when the object is to make a number of veſſels exactly ſimilar to each other, the ſize is generally determined by a gauge fixed without the circumference of the revolving wheel, but projecting over it in ſuch a manner that, whenever the yielding clay is ſpread out until it touch this gauge, the artiſt knows that the article which he is making has attained the exact figure which he intends.

The potter's wheel has lately been much improved by adapting a ſtrap to it, which paſſes over a large taper cylinder of wood, and by means of which the artiſt is enabled to increaſe or diminiſh the rapidity of the motion at pleaſure. This contrivance is known to mechanics by the name of the *cone pulley*. Parkes's Eſſays, vol. iii. See POTTERY.

WHEELS, *Tires of*, the iron hoops or bars which are put round the outſides of the felly-parts of them.

Windmill

Wind-*Mill*, in *Mechanics*, a machine which is put in motion by the force of the wind. Wind-mills are in general applied to the purpoſe of grinding corn, but are occaſionally uſed to give motion to machines for raiſing water, ſawing-mills, or for other purpoſes. We ſhall in this article conſider the wind-mill as a firſt mover, or *primum mobile*, which may be applied to many purpoſes.

The invention of wind-mills is not of very remote date. According to ſome authors they were firſt uſed in France in the ſixth century; while others maintain that they were brought to Europe in the time of the cruſades, and that they had long been employed in the Eaſt, where the ſcarcity of water precluded the application of that powerful agent to machinery.

The wind-mill, though a common machine, has ſome things in it more ingenious than is uſually imagined. Add, that it is commonly allowed to have a degree of perfection, which few of the popular engines have attained to, and which the makers are but little aware of: though the aid of mathematics has furniſhed ample matter for its improvement.

The vertical wind-mill, which is the kind in moſt common uſe, conſiſts of an axis or ſhaft A B, (*fig.* 1. *Plate* II. *Wind-Mill,*) placed in the direction of the wind, and uſually inclining a little upwards from the horizontal line. At one end of this, four long arms or yards, S, T, V, W, are fixed perpendicular to the axis, and croſs each other at right angles; into theſe arms ſmall croſs-bars are mortiſed at right angles; and other long bars are joined to them, which are parallel to the length of the arms; ſo that the bars interſect each other in the manner of lattice-work, and form a ſurface, on which a cloth can be ſpread to receive the action of the wind. Theſe are called the ſails; they are in form of a trapezium, and are uſually nine yards long and two wide.

The circular motion is produced by the obliquity of the planes of theſe ſurfaces, from the plane in which all the four arms are ſituated; by theſe means, when the wind blows in the direction of the axis, it does not impinge upon the ſails at right angles to their ſurfaces, but ſtrikes obliquely; hence the effort of the ſail to recede from the wind, cauſes it to turn round with the common axis, and the four ſails are all made oblique in the ſame direction, ſo as to unite their efforts for the common object.

That the wind may act with the greateſt efficiency upon the ſails, the wind-ſhaft muſt have the ſame direction as the wind. But as this direction is perpetually changing, ſome apparatus is neceſſary for bringing the wind-ſhaft and ſails into their proper poſition: this is done by turning the axis and ſails round in an horizontal direction. There are two methods of effecting this. In the old mills, like *fig.* 1, the whole of the mill or building which contains the machinery is ſuſtained upon a vertical poſt, firmly fixed as a ſtand or foot, upon which the whole machine can be turned by a lever, to preſent the ſails to any quarter of the horizon from whence the wind blows; and hence theſe are called poſt wind-mills, and are neceſſarily made of wood. The other kind, *fig.* 2, is called a ſmock-mill, in which only the dome-cap or head, which contains the axis of the ſails, and covers the great cog-wheel, turns round horizontally; the other parts of the machinery being contained in a fixed building, which riſes up in form of a conical tower of maſonry, and is ſurmounted by this moveable cap or dome, which is ſupported on rollers, ſo as to turn round eaſily.

As both the common methods of adjuſting the wind-ſhaft require human aſſiſtance, it would be very deſirable that the ſame effect ſhould be produced ſolely by the action of the wind. This may be done by fixing a large wooden vane or weathercock at the extremity of a long horizontal arm, which lies in the ſame vertical plane with the wind-ſhaft.

By theſe means, when the ſurface of the vane and its diſtance from the centre of motion are ſufficiently great, a very gentle breeze will exert a ſufficient force upon the vane to turn the machinery, and will always bring the ſails and wind-ſhaft to their proper poſition. This weathercock, it is evident, may be applied either to machines which have a moveable roof, or to thoſe which revolve upon a vertical arbor. This method is practiſed in ſmall machines; but a vane of ſufficient power to turn a large mill about would be unwieldy. A much better method is therefore practiſed in the beſt mills, as we ſhall ſoon deſcribe.

In a *poſt-mill* the building muſt neceſſarily be of ſmall ſize, and it can only contain one pair of mill-ſtones. For this purpoſe, a large cog-wheel is fixed upon the main-ſhaft or axis of the ſails; the cogs are placed in the face or flat ſurface of the wheel, and act upon the teeth of a pinion, which is fixed upon the vertical axis or ſpindle of the mill-ſtones. The mill-houſe is of a rectangular figure, but narrow in the direction which is preſented to the wind: it is two ſtories high, the main-ſhaft and mill-ſtones being in the upper chamber, whilſt the lower is only uſed to contain ſacks of flour, and alſo to receive the poſt on which the mill turns round horizontally to face the wind. This poſt is a very ſtrong tree, and is held perpendicularly by fixing it upon the middle of long timbers, which form a large croſs on the ground, and are the baſement of the whole mill. The poſt is fixed perpendicularly by means of ſeveral oblique braces, extending from the ground-croſs to the middle part of the poſt; but ten or twelve feet of the upper end of the poſt muſt be round, and clear from the obſtruction of the braces. This part of the poſt riſes up through the middle of the lower chamber, in the floor of which a circular collar is formed, to ſurround the lower part of the poſt exactly. At the upper end of the poſt is a pivot or gudgeon, which enters into a ſocket fixed in the middle of the upper floor, and to one of the ſtrongeſt croſs-beams, becauſe this beam muſt ſuſtain the whole weight of the mill. In this manner, the whole mill can turn about upon the vertical poſt, but remains always in equilibrio. To make it firm, and prevent it from turning about at every moment, a ſtrong framing is united by joints to the back part of the mill-houſe, and deſcends in a ſloping direction till it touches the ground: this is furniſhed with ſteps, ſo that it ſerves as a broad ladder to aſcend to the mill; but another uſe is to ſteady the mill, becauſe the end of this frame, which is very heavy, reſts on the ground, and ſhort poſts are fixed in a circle round the mill at regular intervals, to which the end of the ladder is faſtened with cords. In order to turn the mill about, a rope is faſtened to the end of the ſloping ladder, and is carried up to the top of the mill in an inclined direction. By means of a ſtrong lever, or a tackle of pulleys, this rope can be ſhortened, ſo as to lift up the ladder clear of the ground; and then, by puſhing it like a long lever, the whole mill is turned round. To obtain more force, a ſmall capſtan is often provided to draw

a rope attached to the end of the ladder. This capſtan is moveable, and is faſtened at pleaſure to any one of the poſts which are fixed in the ground.

The internal mechaniſm of a poſt wind-mill is exhibited in *fig.* 3. *Plate* II. *Wind-Mill.* A H O is the upper room; H *o z* the lower one; A B the axis paſſing through the mill; S, T, V, W, the ſails, covered with canvas, ſet obliquely to the wind, and turning round in the order of the letters in *fig.* 1; C the cog-wheel, having about forty-eight cogs, which carry round the lantern E, having eight or nine rounds, together with its ſpindle G N; K is the upper mill-ſtone, and L the lower one; Q R is the bridge ſupporting the axis or ſpindle G N; this bridge is ſupported by the beams *c* and X Y, wedged up at *c* and Q; *z* Y is the lifting-tree, which ſtands upright; *a b* and *e f* are levers, whoſe centres of motion are *a* and *u*; *f g h i* is a cord, with a ſtone, *i*: it goes about the pins *g* and *h*, to wind up and raiſe the ſtone at pleaſure. The ſpindle *t* N is fixed to the upper mill-ſtone K, by a piece of iron called the rynd, and fixed in the lower ſide of the ſtone, which is the only one that turns about, and its whole weight reſts upon a hard ſtone, fixed in the bridge Q R at N. The trundle E, and axis G *t*, may be taken away; for it reſts by its lower part at *t* by a ſquare ſocket, and the top runs in the edge of the beam *w*. By bearing down the end *f* of the lever *f e*, *b* is raiſed, which raiſes *z* Y, and this raiſes Y X, which lifts up the bridge Q R, with the axis N G, and the upper ſtone K; and thus the ſtones are ſet at any diſtance. The lower immoveable ſtone is fixed upon ſtrong beams, and is broader than the upper one: the flour is conveyed through the tunnel *n o* into a cheſt; P is the hopper, into which is put the corn, which runs along the ſpout *r* into the hole *t*, and ſo falls between the ſtones, where it is ground. The axis G *t* is ſquare, which ſhaking the ſpout *r*, as it goes round, makes the corn run out; *r s* is a ſtring going about the pin *s*, and ſerving to move the ſpout nearer to or farther from the axis, ſo as to make the corn run faſter or ſlower, according to the velocity and force of the wind. And when the wind is great, the ſails S, T, V, W, are only in part or one ſide covered; or perhaps only one half of two oppoſite ſails. Toward the end B of the axis another cog-wheel may be fixed, with a trundle and mill-ſtones, like that already deſcribed; ſo that the ſame axis moves two ſtones at once; and when only one pair is to grind, the trundle E, and axis G *t*, are taken out from the other; *x y l* is a girt or gripe of pliable wood, fixed at the end *x*; and the other end *l* is tied to the lever *k m*, moveable about *k*; and the end *m* being put down, draws the gripe *x y l* cloſe to the cog-wheel; and thus the motion of the mill is ſtopped at pleaſure; *p q* is a ladder for aſcending to the higher part of the mill; and the corn is drawn up by means of a rope, rolled about the axis A B, when the mill is at work.

The ſtructure of the mill-ſtones, or grinding parts, is the ſame as the water-mills. See MILL.

It is plain that this conſtruction confines all the machinery to the two chambers, or that part of the mill which is poiſed upon the vertical poſt; hence this kind of wind-mill is unfit for any other purpoſes than that of grinding corn, and for expreſſing oil, becauſe there is ſo little room for the machinery. The Dutch, who are famous for wind-mills, make them ſometimes with a very large poſt, which has a hole down through the centre of it, like a trunk, and through this, a perpendicular axis paſſes to convey the power of the mill down into a building below, and upon the top of which, as a roof, the foundation-beams of the poſt are fixed. (See *fig.* 4.) In this way, the mill is applied to ſaw wood, or to make paper, or any other purpoſe; but the conſtruction is complicated, and leſs effective than the other kind of mill, in which only the head or top turns round, as we ſhall now deſcribe.

The Smock-Mill.—This is the beſt kind of mill, becauſe the building which contains the machinery may be made of any required dimenſions, the ſails and turning cap being all at the top of the houſe. *Fig.* 3. in *Plate* I. *Wind-Mill*, is a vertical ſection of one of theſe mills. K K are the walls of the houſe, and O O ſtrong timbers forming a roof to it; upon theſe eight principal timbers H are erected, to form an octagonal pyramid of carpentry, the ſides of which are filled up by diagonal bracing, and ſmall uprights to nail the boarding to.

The four ſails are fixed on an iron axis B N, by ſcrewing them to an iron croſs formed at one end of it. Two of theſe ſails are marked A A; but the other two are end-ways, and cannot be ſeen. Upon the axis within the mill the cog-wheel C is fixed; and this turns a trundle or lantern D, fixed on the upper end of a ſtrong vertical ſhaft, E E, extending from the top to the bottom of the mill, to turn the machinery: on the lower end of it is a large wheel, *f f*, which turns two pinions, *g g*, upon the ſpindles of the mill-ſtones *h h*. Theſe are on the ſame conſtruction as thoſe deſcribed in our article MILL, to which we refer. At *l* is a wheel upon the main axis, giving motion to a pinion on a horizontal ſhaft or roller, *k*, which has a rope wrapped upon it, to wind up the ſacks of corn. The wheel *l* alſo turns a ſimilar horizontal axis with ſeveral wheels, to receive endleſs ropes for turning the bolting and dreſſing machines.

We will now enter more fully into the mechaniſm of the upper part of the mill, which is called its head or cap, marked G, and contains the axis B N. This is ſupported upon bearings, one being near its ſails, and the other at its extreme end, as is ſhewn in *fig.* 5. *Plate* II. *Wind-Mill*, which is an horizontal ſection of the head, ſhewing the circular kirb, or wooden ring, K, and the framing which is bolted upon it to ſupport the axis.

The conſtruction of the axis is ſhewn in *fig.* 6. of the ſame plate. It conſiſts of an octagonal iron ſhaft with two cylindrical necks at *c* and *d*, where it reſts upon its bearings. At the end it has a kind of box, which has two mortiſes, *e* and *f*, through it in perpendicular directions to receive the ſails. At the back of one of theſe mortiſes, and the front of the other, a projecting arm is left in the caſting to receive ſcrew-bolts, which hold the ſails faſt in the mortiſes. The cog-wheel is fixed on by bolting its arms againſt a flanch C, caſt on the axis. The ſails are braced by a rope-ſtay to each arm, proceeding from the end of a pole, which is fixed at the end of the caſt-iron axis. Each ſail is formed of a ſail-cloth, ſpread upon a kind of lattice-work or framing, compoſed of rails mortiſed into the arms of the ſails. The plane of this frame is inclined to the plane of the ſails' motion at ſuch an angle, that the wind blowing in the direction of the axis acts upon the ſails as inclined planes, and turns them about with a power proportionate to the ſize of the ſails and force of the wind. It is neceſſary, as the wind changes its direction, to turn the ſails about, that the axis may be always in the direction of the wind. (See *fig.* 3. *Plate* I.) This motion is effected by turning the head of the mill round upon the fixed part, on a circle or kirb at the top of the frame compoſing the houſe of the mill. At the bottom of the frame of the wood-cap is a circular or moveable kirb, between which and the fixed kirb a number of rollers are placed; and the moveable kirb of the cap lies upon theſe rollers, which are kept

equidiſtant from each other by their centre-pins being fitted into a circular hoop: by theſe means, though the head of the mill with the wheels and ſails weigh ſeveral tons, they can be made to turn round to face the wind by a ſlight power.

The head is contrived to turn itſelf about whenever the wind changes in the following manner:—A ſmall pair of ſails, or fans, M, are fixed up in a frame L, projecting from the back of the head: it has a pinion of ten leaves upon its axis, engaging in a wheel of 60 teeth upon an inclined axis *b*; and this has a pinion *d* of 12 leaves at the other end of it, turning a bevilled wheel of 72 teeth upon a vertical iron axis, at the lower end of which is a pinion *e* of 11 teeth: this works in a circle of 120 cogs, fixed round on the outſide of the fixed kirb. By theſe means, whenever the fan M is turned, it moves the head of the mill ſlowly round, and with proportionate power.

Now if ever the wind varies in the leaſt from the direction of the main ſhaft of the ſails, it acts obliquely upon the vanes of the fan, and turns them round, at the ſame time ſetting the head right again, ſo that the axis points to the wind. But when the axis is in this ſituation, the wind blows in the planes of the vanes of the fan, and has no effect upon them. The head of the mill is kept firmly in its place when it turns about by rollers; the axles of which are bolted to the inſide of the framing of the head, and the rollers apply to the inſide of the fixed kirb: there are four of theſe rollers. The pivot at the upper end of the vertical ſhaft is ſupported in a bearing bolted to a croſs-beam in the framing of the head of the mill; and this is fixed preciſely in the centre of the head, that it may not vary in its ſituation as the head turns round. Many other things are ſo evident in the drawing as to need little farther explanation; ſuch as the different floors of the building, and the circular gallery, I I, all round the mill, for the miller to go round to take the cloth off the ſails in high winds, or when the mill is to ſtop. This is done by untying the cloth at the extremity of the ſail, and twiſting it up like a rope; then tying the end of it again to the lattice, in which ſtate it preſents no ſurface to the wind. At *k* is a roller turned round by a wheel *l*, fixed on the middle part of the vertical ſhaft: it is uſed to draw up the ſacks of corn from the bottom of the mill into the upper part, which is uſed as a ſtore-houſe for the corn, being divided into as many compartments as the miller requires. The mill-ſtones are made the ſame as thoſe uſed in water-mills. A pair of regulating balls are attached to the upper part of the mill-ſtone ſpindle, to regulate the velocity of the mill. The manner of applying this regulator is explained in *fig.* 5. *Plate* II. *Wind-Mill.* The lower end of the iron ſpindle F is fitted to a ſquare, formed on the top of the mill-ſtone axis, and the pinion *g g* is fixed on the upper end, to give motion to the ſtones: immediately beneath the pinion two rods are jointed, hanging downwards, having a heavy iron ball, *l*, fixed faſt on the lower end of each: two links are jointed to the arms at *m*, and ſuſpend a collar, which is capable of ſliding freely up and down upon the ſpindle F. It is evident that when the balls fly out from the ſpindle by their centrifugal force, that the collar will be elevated, and the contrary when the balls approach the ſpindle. The ſliding collar is embraced by a fork formed at the end of a ſteelyard, lying horizontal, and ſuſpended by the rod *p* as a fulcrum; an iron rod *q* deſcends from the extreme end of the ſteelyard, having its lower end formed to a hook, by which it is connected with a lever, *r*, whoſe fulcrum is *s*; this, by an iron rod *t*, ſuſpends one end of the beam called the bridge, on which the lower pivot of the mill-ſtone axis reſts, the other end bearing on a fulcrum or centre. Now it follows from this arrangement of levers, that by elevating the forked end of the ſteelyard, or the ſliding collar, that the ſpindle of the ſtones will be ſuffered to deſcend a very minute quantity. This regulates the velocity of the mill, becauſe when the wind increaſes, and the motion of the mill is accelerated, the balls fly out by the centrifugal force; this lets the upper ſtone down nearer to the lower, thereby increaſing the reſiſtance to the mill, and counteracting the increaſed force of the wind. On the other hand, if the wind falls, and the mill moves more ſlowly in conſequence, the balls fall together, and let down the ſliding collar; this raiſes the ſtone up, and increaſes the diſtance between them, thereby diminiſhing the reſiſtance; for this purpoſe, a weight *o* (*fig.* 5.) is hung upon the ſteelyard, ſufficient to elevate the ſtone whenever the cloſing of the balls and conſequent deſcent of the collar will permit it to do ſo. There are ſeveral notches made in the ſteelyard for different poſitions of the fulcrum *p* and rod *q*; by means of theſe the quantity of the regulation can be adjuſted to the following rule. If when the wind blows ſtronger the mill goes ſlower, contrary to the effect expected, it ſhews that the regulation is too active; then increaſe the leverage of the balls by ſhortening the diſtance between the fulcrum *p* of the ſteelyard and the ſuſpenſion of the rod *q*, by ſhifting either of them into different notches. On the contrary, if the mill goes much faſter when the wind increaſes, it ſhews that the regulation does not act ſufficiently; then increaſe the diſtance between the rod *q* and the fulcrum *p*. If the whole limits of the notches in the ſteelyard ſhould not be ſufficient to effect this, the acting length of the lever *r s* muſt be increaſed or diminiſhed by removing its fulcrum *s* to a greater or leſſer diſtance from the ſuſpending-rod *t*; by means of this contrivance the miller is enabled, without much inconvenience, to regulate the velocity of the ſtones to that degree which is found beſt for reducing the greateſt quantity of grain to flour, without damaging it by heating, as is the caſe when the ſtones move too quick.

Theory of the Motion of a Wind-Mill, with the Poſition of its Sails or Vanes.—The angle which the ſurfaces of the ſails are to make with their common axis, that the wind may have the greateſt effect, or the degree of weathering, as the mill-wrights call it, is a matter of nice inquiry, and has much employed the thoughts of the mathematicians.

To conceive why a wind-mill moves at all, the theory of compound motions muſt be ſuppoſed. A body moving perpendicularly againſt any ſurface, ſtrikes it with all its force. If it move parallel to the ſurface, it does not ſtrike it at all: and if it move obliquely, its motion, being compounded of the perpendicular and parallel motion, only acts on the ſurface, conſidered as it is perpendicular, and only drives it in the direction of the perpendicular. So that every oblique direction of a motion is the diagonal of a parallelogram, whoſe perpendicular and parallel directions are the two ſides. Add, that if a ſurface, which, being ſtruck obliquely, has only received the perpendicular direction, be faſtened to ſome other body, ſo as that it cannot purſue its perpendicular direction, but muſt change it for ſome other; in that caſe, the perpendicular itſelf becomes the diagonal of a new parallelogram, one of whoſe ſides is the direction which the ſurface may follow; and the other, that which it cannot.

Thus, a rudder faſtened obliquely to the keel of a veſſel, being ſtruck by the current of water parallel to the keel, and, of conſequence, obliquely with regard to itſelf; it will appear, by drawing the line of perpendicular impulſe, that it tends to tear the rudder from the keel, and to carry it away: and that this direction, perpendicular to the rud-

der, is oblique to the keel. The rudder, then, would be carried off in an oblique direction; but as, in reality, it is so secured, that it cannot be torn and carried off, we are only to consider, in this compound motion, that of the two directions wherewith it can move without being torn from the keel; and leave the other, which would tear it off, as useless.

Now, the direction in which it can move without parting from the keel, is that which carries it circularly about its extremity, as about a centre. So that the effect of the oblique impulse of the water on the rudder is reduced, first to a perpendicular impression, which is again reduced to the mere turning of the rudder round; or, if the rudder be immoveable, to the turning of the vessel. Now, in an oblique and compound motion, where only one of the directions is of service; the greater ratio the other has to it, the less effect will the motion have, and *vice versâ*. In examining the compound motions of the rudder, we find, that the more oblique it is to the keel, the ratio of the direction that serves to turn it to the other is the greater. But, on the other hand, the more obliquely it is to the keel, and, of consequence, to the course of the water which is supposed parallel to it, the more weakly it strikes. The obliquity of the rudder, therefore, has, at the same time, both an advantage and a disadvantage; but as those are not equal, and as each of them is still varying with every different position of the rudder, they become complicated variously; so that sometimes the one prevails, and sometimes the other.

It has been a point of inquiry to find the position of the rudder, in which the advantage should be the greatest. M. Renau, in his famous theory of the working of ships, has found, that the best situation of the rudder is, when it makes an angle of fifty-five degrees with the keel. See Rudder.

If, now, a wind-mill, exposed directly to the wind, should have its four sails perpendicular to the common axis in which they are fitted, they would receive the wind perpendicularly; and it is visible that impulse would only tend to overturn them. There is a necessity, therefore, to have them oblique to the common axis, that they may receive the wind obliquely.

For the greater ease, let us only consider one vertical sail. The oblique impulse of the wind on this sail is reducible to a perpendicular impulse; and that direction, as the sail cannot absolutely keep to it, is compounded of two; one of which tends to make it turn on its axis, and the other to fall backwards. But it is only the first of these directions that can be obeyed. Of consequence, the whole impulse of the wind on the sail has no other effect but to make it turn from right to left, or from left to right, as its acute angle turns this way or that. And the structure of the machine is so well contrived, that the three other sails are determined, from the same causes, to move the same way.

The obliquity of the sails, with regard to their axis, has precisely the same advantage and disadvantage with the obliquity of the rudder to the keel. And M. Parent, seeking, by the new analysis, the most advantageous situation of the sails on the axis, finds it precisely the same angle of fifty-five degrees.

For the farther illustration of this point, let A B (*Plate* II. *Wind-Mill*, *fig.* 7.) be the axis of the mill, C D a sail, and its angle of obliquity (*viz.* that which it makes with the axis) be E C G; then if G C be the force of the wind in the direct position of the sail, G E (the sine of the angle of incidence G C E) will be the force of the wind in its oblique position; but the force of G E is resolvable into two others, E F and G F; of which the latter, being parallel to the axis, avails nothing in turning the sails about it; but the other, E F, being perpendicular to it, is wholly spent in compelling the sail to turn round. The force of the wind on the sail will be as the square of the sine of incidence, or as GE^2; and if the area of the sail, and the velocity of the wind, be supposed constant, the force of the wind in the direct position will be to that in the oblique one, as GC to GE^2; but when GE is the whole force, that part which turns the sail is represented by EF;

and $GE : EF\ (:: GC : CE) :: GE^2 : \frac{CE \times GE^2}{GC}$

= to the force which turns the sail, when the whole force is represented by GE^2 This expression $\frac{CE \times GE^2}{GC}$ begins from nothing, when the angle of incidence begins to be oblique, and increases with the obliquity of the said angle to a certain number of degrees; because that part of the force which is parallel to the axis, becomes less in proportion to that which is perpendicular to it; but after it has passed this limit, it again decreases, and becomes nothing, when the angle of incidence vanishes. There is, therefore, one certain position of the sail, in which the force of the wind upon it is a *maximum*. In order to find this, put radius $GC = a$, $EC = x$; and we have $GE^2 = aa - xx$, and consequently the force $\frac{CE \quad GE^2}{GC} = \frac{aax - xxx}{a}$, which must be a *maximum*: therefore its fluxion $\quad - 3x^2\dot{x} = 0$: whence $aa = \quad xx$, and so $x = \sqrt{\frac{aa}{2}}$ = (in logarithms) $\frac{20.000000 - 0.477121}{2} = 9.761439$, which is the logarithmic sine of the angle $35° 16' = CGE$; and therefore the angle $ECG = 54° 44'$, when the force of the wind is a *maximum*. Thus, also, if lm (*fig.* 7.) parallel to the axis Q M, be equal to a, and represent the whole force of the wind on the sail; this force is reduced to ln, and this again to no, which acts perpendicularly to the axis, and turns the sail. This force, putting $mn = x$, is expressed by $\frac{aax - x^3}{a}$ and thus, as before, when it is a *maximum*, $x = \sqrt{\frac{aa}{3}} = a\sqrt{\frac{1}{3}}$; and the angle $lmn = 54° 44'$. Martin's Phil. Brit. vol. i. p. 220, vol. ii. p. 212.

This angle, however, is only that which gives the wind the greatest force to put the sail in motion, but not the angle which gives the force of the wind a *maximum* upon the sail when in motion: for when the sail has a certain degree of motion, it yields to the wind; and then that angle must be increased, to give the wind its full effect. Mr. Maclaurin, in his Fluxions, vol. ii. p. 734. has shewn how to determine this angle.

It may be observed, that the increase of this angle should be different, according to the different velocities from the axis to the extremity of the vane or sail. At the axis it should be 54° 44', and thence continually increase, giving

the vane a twist, and so causing each rib of the vane to lie in a different plane.

It is observed, that the ribs of the vane or sail ought to decrease in length from the axis to the extremity, giving the vane a curvilineal form; so that no part of the force of any one rib be spent upon the rest, but all move on independent of each other. The twist above-mentioned, and the diminution of the ribs, are exemplified in the wings of birds. As the end of the sail nearest the axis cannot move with the same velocity which the tips or farthest ends have, although the wind acts equally strong upon them, Mr. Ferguson (Lect. on Mechanics, p. 52.) suggests, that perhaps a better position than that of stretching them along the arms directly from the centre of motion, might be to have them set perpendicularly across the farther ends of the arms, and there adjusted lengthwise to the proper angle. For, in that case, both ends of the sails would move with nearly the same velocity; and being farther from the centre of motion, they would have so much the more power, and then there would be no occasion for having them so large as they are generally made; which would render them lighter, and, consequently, there would be so much the less friction on the thick neck of the axle, when it turns in the wall.

M. Parent considered what figure the sails of a wind-mill should have, to receive the greatest impulse from the wind; and he determined it to be a sector of an ellipsis, whose centre is that of the axis, or arbor, of the mill; and the little semi-axis the height of thirty-two feet: as for the greater, it follows necessarily from the rule that directs the sail to be inclined to the axis, in an angle of 55 degrees.

On this foundation he assumes four such sails, each of which is one-fourth of an ellipsis; which, he shews, will receive all the wind, and lose none, as the common ones do. These four surfaces, multiplied by the lever with which the wind acts on one of them, express the whole power the wind has to move the machine, or the whole power the machine has when in motion.

The same manner of reasoning, applied to a common wind-mill, whose sails are rectangular, and their length about five times their breadth, shews, that the elliptic wind-mill has about seven times the power of the common one.

A wind-mill with six elliptic sails, he shews, would still have more power than one with only four. It would only have the same surface with the four, since the four contain the whole space of the ellipsis as well as the six. But the force of the six would be greater than that of the four, in the ratio of 245 to 231. If it were desired to have only two sails, each being a semi-ellipsis, the surface would be still the same; but the power would be diminished by near one-third of that with six sails, because the greatest of the sectors would much shorten the lever with which the wind acts.

Best Form and Proportion of rectangular Wind-Mills.— As elliptical sails would be something so new, that there is little room to expect they will come into common use, the same author has considered which form, among the rectangular ones, will be the most advantageous. And by the method *de maximis et minimis*, he finds it very different from the common ones.

The result of this inquiry is, that the width of the rectangular sail should be nearly double its length; whereas the length is usually made almost five times the width. Add, that as we call length the dimension which is taken from the centre of the axis, the greatest dimension of the new rectangular sail will be turned toward the axis, and the smallest from it; quite contrary to the position of the common sails.

The power of a wind-mill with four of these new rectangular sails, M. Parent shews, will be to the power of four elliptic sails, nearly as 13 to 23; which leaves a considerable advantage on the side of the elliptic ones; yet will the force of the new rectangular sails be considerably greater than that of the common ones.

M. Parent likewise considers what number of the new sails will be most advantageous; and finds, that the fewer the sails, the more surface there will be, but the less power. The ratio of the power of a wind-mill with six sails will be to another with four, nearly as 14 to 13. And the power of another with four will be to that with two, nearly as 13 to 9.

For a variety of curious experiments and observations concerning the construction and effects of wind-mill sails, by the ingenious Mr. Smeaton, see Phil. Transf. vol. ii. p. 138, &c.

Mr. Smeaton's experiments did not realize M. Parent's theory; for he found the sails fixed at the angle of 55 degrees with the axis, to be the least advantageous of any which he tried; but if the sails are included from 72 to 75 degrees from the axis, or 15 to 18 degrees to the place of their motion, the greatest effect will be produced that can be when the sails are plane surfaces.

He also found, that the elliptical sails, which intercept the whole cylinder of wind, do not produce the greatest effect, for want of proper interstices for the wind to escape.

The following maxims, deduced by Mr. Smeaton from his experiments, contain the most accurate information upon the subject.

Maxim 1.—The velocity of wind-mill sails, whether unloaded or loaded, so as to produce a maximum effect, is nearly as the velocity of the wind, their shape and position being the same.

Maxim 2.—The load at the maximum is nearly, but somewhat less than, as the square of the velocity of the wind, the shape and position of the sails being the same.

Maxim 3.—The effects of the same sails at a maximum are nearly, but somewhat less than, as the cubes of the velocity of the wind.

Maxim 4.—The load of the same sails at the maximum is nearly as the squares, and their effects as the cubes of their number of turns in a given time.

Maxim 5.—When sails are loaded, so as to produce a maximum at a given velocity, and the velocity of the wind increases, the load continuing the same: 1st, The increase of effect, when the increase of the velocity of the wind is small, will be nearly as the squares of those velocities. 2dly, When the velocity of the wind is double, the effects will be nearly as 10 to 27½. But, 3dly, When the velocities compared are more than double of that where the given load produces a maximum, the effects increase nearly in the simple ratio of the velocity of the wind.

Maxim 6.—In sails where the figure and positions are similar, and the velocity of the wind the same, the number of turns in a given time will be reciprocally as the radius or length of the sail.

Maxim 7.—The load at a maximum that sails of a similar figure and position will overcome, at a given distance from the centre of motion, will be as the cube of the radius.

Maxim 8.—The effects of sails of similar figure and position are as the square of the radius.

Maxim 9.—The velocities of the extremities of the sails, in all their usual positions, when unloaded, or even

loaded to a maximum, are confiderably quicker than the velocity of the wind.

Rules for modelling the Sails of Wind-Mills.—Fig. 4. *Plate* II. *Wind-Mill*, is a front view of one of the four fails of a wind-mill. The letters of reference will ferve to explain the terms made ufe of in the following defcription.

1. The length of the arm or whip A A, reckoned from the centre of the great fhaft B, to the outermoft bar 19, governs all the reft.

2. The breadth of the face of the whip A, next the centre, is one-thirtieth of the length of the whip; its thicknefs at the fame end is three-fourths of the breadth; and the back-fide is made parallel to the face for half the length of the whip, or to the tenth bar; the fmall end of the whip is fquare, and as its end is one-fixtieth of the length of the whip, or half the breadth at the great end.

3. From the centre of the fhaft B, to the neareft bar 1 of the lattice, is one-feventh of the whip; the remaining fpace of fix-fevenths of the whip is equally divided into nineteen fpaces, fo as to make nineteen bars; one-ninth of one of thefe fpaces is equal to the mortifes for the bars, the tenons of which are made fquare where they enter and go through the whip, and confequently the mortifes muft be fquare alfo.

4. To prepare the whip for mortifing, ftrike a gage-fcore at about three-fourths of an inch from the face on each fide, and the gage-fcore, on the leading fide 4, 5, will give the face of all the bars on that fide; but on the other fide, the faces of all the bars will fall deeper than the gage-fcore, according to a certain rule. To find the fpace to be fet off for this purpofe for each bar, conftruct a fcale in the following manner.

5. Extend the compaffes to any diftance at pleafure, fo that fix times that extent may be greater than the breadth of the whip at the feventh bar; fet thofe fix fpaces off upon a ftraight line for a bafe, at the end of which raife a perpendicular; fet off three fpaces upon the perpendicular, and divide the two fpaces that are fartheft from the bafe line into fix equal parts each, fo that this quantity of two fpaces may be equally divided into twelve fpaces marked out by thirteen points; from each of thefe points draw a line to the oppofite end of the bafe, as fo many rays to a centre, and the fcale is finifhed.

6. To apply this fcale to any given cafe, fet off the breadth of the whip at the laft bar, (that is, the bar at the extremity of the fail,) from the centre of the fcale along the bafe towards the perpendicular; and at this point raife a perpendicular to cut the ray neareft to the bafe; alfo fet off the breadth of the whip at the feventh bar in the fame manner, and at this point erect another perpendicular to cut the thirteenth radius. From the interfection of the perpendicular (drawn upon the breadth of the laft bar) with the firft of the thirteen radii, to the interfection of the other perpendicular with the thirteenth radius, draw an oblique line cutting all the reft, and the diftances of each of thefe laft-mentioned points of interfection from the bafe line is the fpace which the face of each bar is diftant from the gage-line on the driving fide.

7. Thefe diftances give a different fet-off for each bar till the feventh, which fame muft be fet off for all the reft to the firft.

8. The mortifes muft be fquare to the leading fide of the whip.

9. When the mortifes are cut, let the face of the whip be floped off fo as to agree with the face of the bars in every part.

10. Two-fifths of the whip are the length of the laft or longeft bar.

11. Five-eighths of the longeft bar muft be on the driving fide of the whip, and three-eighths on the leading fide, each being reckoned from the middle of the whip.

12. The proportion of the mortifes already given determines the fize of the bars at the mortifes, but their thicknefs muft be diminifhed each way, fo as to be only one-half at the ends; but the face muft be kept of equal breadth all the way.

13. The leading fide goes no farther than the fourth bar, and there only projects one-third of the projection of the laft bar.

14. All the bars on the driving fide are made hollowing in the arch of a circle, which begins to fpring one-third of the length of the bars on the driving fide from the whip; and the fweep is fuch, that if a ftraight line is applied to the face of the bar from the whip to the end, the face of the bar fhould leave the ftraight line about the breadth of the bar.

15. There ought to be three uplongs, as 3, 2, 10, *fig.* 4, to the driving, and two to the leading fide, as at 5, 4, to ftrengthen the lattice.

Self-regulating wind-mills are thofe which adapt themfelves to the irregularities of the wind, by diminifhing or increafing the furface on which the wind can act to turn them round. If the wind increafes in force, the furface expofed to its action is diminifhed; on the contrary, if it decreafes in force, the furface will be increafed in the fame proportion, fo as in fome meafure to render their motion uniform.

The following felf-regulating wind-mill is ftated as the invention of Mr. Andrew Mickle in 1772, the inventor of the threfhing-machine. The length of the fail was divided into eleven compartments, by the bars forming a number of oblong openings, which were each filled up by a fquare frame of wood covered with canvas, and mounted on pivots at their ends; one pivot turning in a hole in the whip, and the other in the bar which lies parallel to it, in the manner of a Venetian blind: the pivots were not placed in the middle of the breadth of the frames, but at one-third from that edge, towards the fhaft or axis of the fails. On the end of each pivot which enters the whip a fmall roller is fixed, round which a chain paffes, and its end is attached to a fteel fpring, placed at right angles to the whip, and in the direction of the length of the canvaffed frames. Now, if the wind blows too hard, it acts to turn the frames edgeways, in which cafe the wind paffes through the fails, and exerts lefs force to turn them round; but as foon as the wind becomes moderate, the fteel fpring brings up the frames into a plane, prefenting their whole furface to its action. A rod of iron extends the whole length of the whip, and is connected with the feveral fprings, to afford the means of ftrengthening or diminifhing their action, according to the feafon of the year. This rod was formed into a fcrew at its outer extremity, and a nut put on to enable the miller to adjuft the ftrength of the fprings conveniently, from the circular gallery furrounding the outfide of the mill.

Mr. William Cubit of North Walfham, in the county of Norfolk, took out a patent, in 1807, for a method of equalizing the motion of wind-mill fails. It is fimilar to Mr. Mickle's, in the fails being made like a Venetian blind; but inftead of the fprings, he applied racks and pinions on the ends of the blind pivots, and a fliding rod, which paffed in a fmall hole made through the length of the axis of the fails; the end of this rod within the mill was

made into a rack, working in a wheel upon which a weight was hung. By this means, when the wind blows too hard, the blinds turn upon their pivots, and by the racks draw out the rod which paſſes through the axis, and raiſe the weight; but as ſoon as the wind abates, the weight brings the blinds to their former poſition.

A patent was granted in 1804 to Mr. John Bywater of Nottingham, for a method of clothing and unclothing the ſails of wind-mills while in motion. The invention conſiſts in a manner of rolling or folding up, and unfolding again, the cloths of common wind-mill ſails while in motion. It is effected by placing a long roller in the direction of the length of the whip round which the cloth is rolled; the inner end of the roller is furniſhed with a pinion, which engages in the teeth of a circular ring of cogs fixed to the ſhaft-head, cloſe behind the back-ſtocks, with the liberty of turning round independent of the ſhaft. Another roller is placed at the back-ſide of the ſail, round which ſeveral cords paſs, and are conveyed over pulleys at the edge of the ſail, and then made faſt to the cloth at different diſtances along its length. The object of this ſecond roller is to clothe the ſail, in the ſame manner as the firſt-mentioned roller unclothed it. The inner end of the back roller is furniſhed with a bevelled pinion, which acts in the teeth of a ring of cogs placed concentric with the one before deſcribed, which has alſo the liberty of turning round independent of the ſhaft. Suppoſe the ſails to be completely clothed, and turning round by the wind, the two rings of cogs revolve with the axis, and therefore produce no effect on the pinions; but if the wind blows too violent, and it becomes neceſſary to partly unclothe the ſails, the miller pulls a cord which is connected with a lever in the head of the mill. This lever comes in contact with a projection on the ring of cogs belonging to the rollers, upon which the cloth winds. Now it is evident, that if the ring of cogs is held faſt, and the ſails continue to revolve, it will cauſe the pinions to turn round and roll up the cloth upon the rollers; on the contrary, if the wind falls, the ſails will require to be more clothed, which is effected by the ſame lever being moved farther, ſo as to quit the ring of cogs it held before, and hold the other faſt, which will put the rollers at the back of the ſails in motion, and by winding the cords upon them, draw the cloth off the ſail-roller, which increaſes the ſurface for the wind to act upon. We have not entered into the minute details of this invention, as given in the patent, for it would have exceeded our limits, but only given a ſufficient deſcription to enable a perſon to underſtand the means of effecting the regulation.

Horizontal Wind-Mills.—Theſe are of various kinds; but only one kind that we know of has been put to any valuable uſe.

Horizontal wind-mills were a favourite ſpeculation a century ago; and the Theatrum of the celebrated Leopold contain a great variety, but they are all upon one or other of two principles. In one of theſe, a very large wheel, like a water-wheel, is mounted with its axis in a perpendicular direction. It conſiſts of ſeveral circular wheels fixed upon the axis; and it has large boards or vanes fixed parallel to its axis, and arranged at equal diſtances round the circular wheels. Upon theſe vanes the wind can act to blow the wheel round; but if the wind were to act upon the vanes at both ſides of the wheel at once, it would have no tendency to turn the wheel round; hence one ſide of the wheel muſt be ſheltered from the wind, whilſt the other is ſubmitted to its full action. For this purpoſe, the whole wheel is incloſed within a large cylindrical framing of wood, which is furniſhed with doors or ſhutters on all ſides to open at pleaſure, and admit the wind, or to ſhut and ſtop it. If all the ſhutters on one ſide are open, whilſt all thoſe on the oppoſite ſide are ſhut, the wind, acting with undiminiſhed force on the vanes at one ſide, whilſt the oppoſite vanes are under ſhelter, turns the mill round; but whenever the wind changes, the diſpoſition of the open vanes muſt be altered, to admit the wind to ſtrike upon the vanes of the wheel in the direction of a tangent to the circle in which the vanes move. A horizontal wind-mill is thus deſcribed in Leopold's Theatrum Machinarum for grinding corn with one pair of ſtones. A ſtrong upright axis is ſo poiſed on a pivot at the lower ends, and ſuſtained in a collar or bearing, as to turn round. Into this ſeveral long arms are fixed, in the manner of radii, and at the extreme ends of each arm a vane is fixed, to receive the action of the wind. Theſe vanes are made of two or more moveable leaves, which cloſe up flat like a book, when they are at that ſide of the circle which moves in a direction to advance towards the wind; ſo that only the edges of the boards are oppoſed to the wind; but when theſe vanes arrive at the oppoſite ſide of the wheel, ſo that the wind blows upon them, the leaves fly open, and expoſe their full ſurfaces to the wind, and receive the impulſe thereof.

A horizontal wind-mill is deſcribed by Dr. Hooke in the Philoſophical Collections for 1681. It conſiſted of four vanes mounted upon vertical axes, and arranged round in a circle by the upper and lower pivots of the vanes being received into holes in the rims of two horizontal wheels fixed upon the ſame vertical ſhaft. The vanes were diſpoſed in ſuch a manner, that on one ſide of the wheel each vane preſented its ſurface to the wind, whilſt the one on the oppoſite ſtood edgeways, ſo as to move through the air without much reſiſtance. This was effected by cog-wheels placed on the lower pivots of the vanes, and ſo arranged, that as one vane turned round upon its pivots, the whole number moved together, and the motion was given to them by a cog-wheel fixed faſt to the framing over the wheel, but concentric with it. This wheel communicated, by means of an intermediate wheel, with the wheels on the axes of the vanes.

The action of this machine is as follows:—Suppoſe the wind blowing at the wheel; it acts againſt that vane which is at right angles to its motion, to turn the wheel round upon its axis. The oppoſite vane preſenting its edge to the wind oppoſes very little reſiſtance. The motion of the wheel upon its axis turns the vanes round upon their pivots, by means of the fixed cog-wheel before deſcribed; ſo that by the time that one has paſſed out of the direction of the wind, another arrives in the ſame perpendicular poſition; and when the wheel has made half a revolution, the vane which ſtood edgeways will be perpendicular to the wind, and the one which before ſtood perpendicular will be edgeways; thus a continued motion is produced without the wheel being caſed up.

Horizontal wind-mills, which are incloſed in a houſe with blinds on all ſides, are very fully deſcribed in Jacob Leopold's Theatrum Machinarum, 1724; but we believe they were firſt practiſed in this country by captain Hooper, who erected one at Margate, and another at Batterſea. The latter is upon a very large ſcale, and is uſed for grinding corn; but at preſent it does not work with much advantage, as the repairs are more conſiderable in proportion to the power it exerts, than in the mills with ſails conſtructed in the common manner.

In *Plate Wind-Mill*, *fig.* 1, is an upright ſection, and *fig.* 2.

a plan of the horizontal mill erected at Margate by captain Hooper. H H are the side walls of an octagonal building which contains the machinery. These walls are surmounted by a strong timber-framing G G, of the same form as the building, and connected at top by cross-framing to support the roof, and also the upper pivot of the main vertical shaft A A, which has three sets of arms, B B, C C, and D D, framed upon it at that part which rises above the height of the walls. The arms are strengthened and supported by diagonal braces, and their extremities are bolted to octagonal wooden frames, round which the vanes or floats E E are fixed, as seen in outline in *fig.* 2, so as to form a large wheel resembling a water-wheel, which is less than the size of the house by about eighteen inches all round. This space is occupied by a number of vertical boards or blinds F F, turning on pivots at top and bottom, and placed oblique, so as to overlap each other, and completely shut out the wind, and stop the mill, by forming a close case surrounding the wheel; but they can be moved all together upon their pivots to allow the wind to blow in the direction of a tangent upon the vanes on one side of the wheel, at the time the other side is completely shaded or defended by the boarding. The position of the blinds is clearly shewn at F F, *fig.* 2. At the lower end of the vertical shaft A A, a large spur-wheel *a a* is fixed, which gives motion to a pinion *c*, upon a small vertical axis *d*, whose upper pivot turns in a bearing bolted to a girder of the floor N. Above the pinion *c*, a spur-wheel *e* is placed, to give motion to two small pinions *f*, on the upper ends of the spindles *g* of the mill-stones *h*. Another pinion is situated, at the opposite side of the great spur-wheel *a a*, to give motion to a third pair of mill-stones, which are used when the wind is very strong; and then the wheel turns so quick, as not to need the extra wheel *e* to give the requisite velocity to the stones. The weight of the main vertical shaft is borne by a strong timber *b*, having a brass box placed on it to receive the lower pivot of the shaft. It is supported at its ends by cross-beams mortised into the upright posts *b b*, as shewn in the plan, *fig.* 2. A floor, or roof, I I, is thrown across the top of the brick building, to protect the machinery from the weather; and to prevent the rain blowing down the opening through which the shaft descends, a broad circular hoop K is fixed to the floor, and is surrounded by another hoop or case L, which is fixed to the arms D D of the wheel. This last is of such a size, as exactly to go over the hoop K, without touching it when the wheel turns round. By this means, the rain is completely excluded from the upper room M, which serves as a granary, being fitted up with bins *m m*, to contain the different sorts of grain which is raised up by the sack-tackle. A wheel *i* is fixed on the main shaft, having cogs projecting from both sides. Those at the under side work into a pinion on the end of the roller *k*, which is for the purpose of drawing up sacks. Another pinion is situated above the wheel *i*, which has a roller projecting out over the flap-doors seen at *p*, in the *fig.* 2, to land the sacks upon. The two pinions *m m*, *fig.* 2, are turned by the great wheel *a a*, and are for giving motion to the dressing and bolting machines, which are placed upon the floor N, but are not shewn in the drawing, being exactly similar to the dressing-machines used in all flour-mills. The cogs upon the great wheel *a* are not so broad as the rim itself, leaving a plain rim about three inches broad. This is encompassed by a broad iron hoop, which is made fast at one end to the upright post *b*; the other being jointed to a strong lever *n*, to the extreme end of which a purchase *o* is attached, and the fall is made fast to iron pins on the top of a frame fixed to the ground. This apparatus answers the purpose of the brake or gripe used in common wind-mills to stop their motion. By pulling the fall of the purchase *o*, it causes the iron strap to embrace the great wheel, and produce a resistance sufficient to stop the wheel. The mill can be regulated in its motion, or stopt entirely, by opening or shutting the blinds F, which surround the fan-wheel. They are all moved at once by a circular ring of wood situated just beneath the lower ends of the blinds upon the floor I I, being connected with each blind by a short iron link. The ring is moved round by a rack and spindle, which descend into the mill-room below, for the convenience of the miller.

A sort of wind-mill has been long much employed in Portugal, in which, from the difference in the construction of the sails, it is supposed by some, as lord Somerville, who has inspected it when working, to possess a superiority in having the broad part of the sail at the end of the levers or booms; in consequence of which equal resistance is overcome with less length of branches: and that from this shortness a considerable saving is made in the timber of both the booms and spindles, as well as in the height, first cost of the mills, and their future repairs.

The advantages of making use of these sorts of wind-mills in preference to others are, that as there are four booms, as well as four masts for the sails, they are capable of being more easily braced out to the wind, and in case of a sudden gale or gust of it, are more easily cast loose than in those of the common construction; and that as the sails in these mills are placed in the best possible direction by the booms, it is presumed that a wind-mill built on this plan and principle will do more work than any common wind-mill with an equal quantity of canvass.

These sorts of mills have also lately been very much improved by constructing and disposing those surface parts upon which the wind is intended to act, in such a particular manner, as that by alternately opposing a resisting and non-resisting surface, the whole force or impulse may operate in a direct manner upon the resisting side of the sail or vane, in proportion to its extent; and that when the non-resisting side is returning against these powers, the mill being so contrived that there is very little resistance, however large the surface. These improvements, when applied to horizontal wind-mills, the power of them, even with the same quantity of sail, or acting surface, may too be increased or diminished at pleasure, which is a circumstance of very great utility and convenience in many cases.

WIND MILL.

Fig. 3.

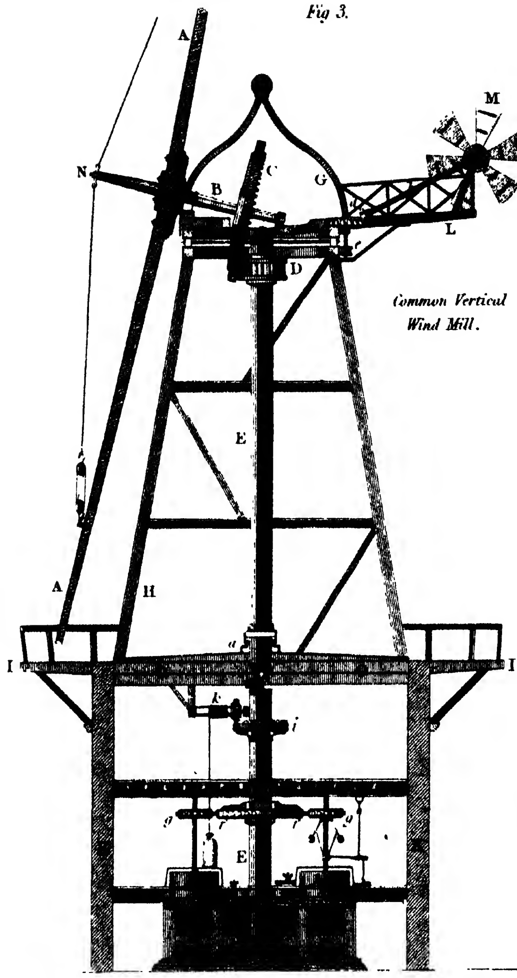


Fig. 1.

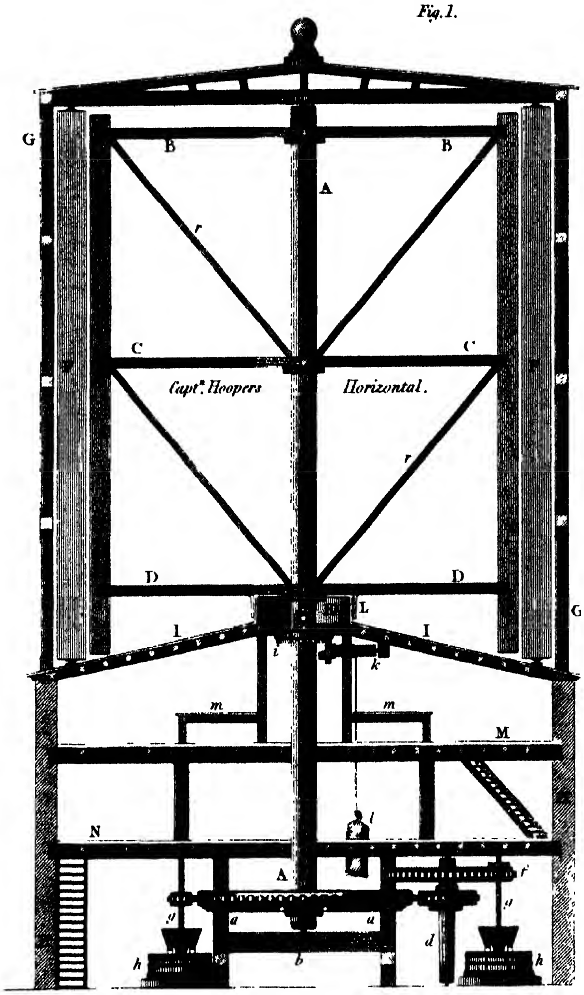


Fig. 5.

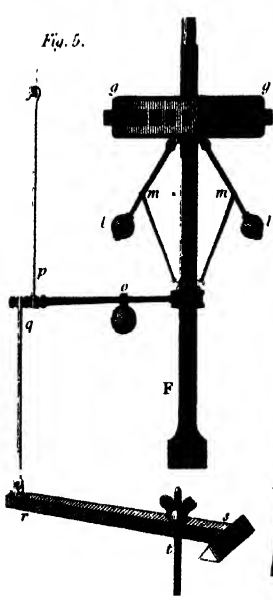


Fig. 4.

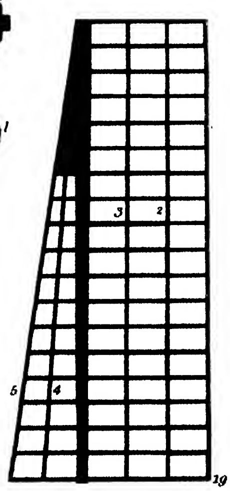
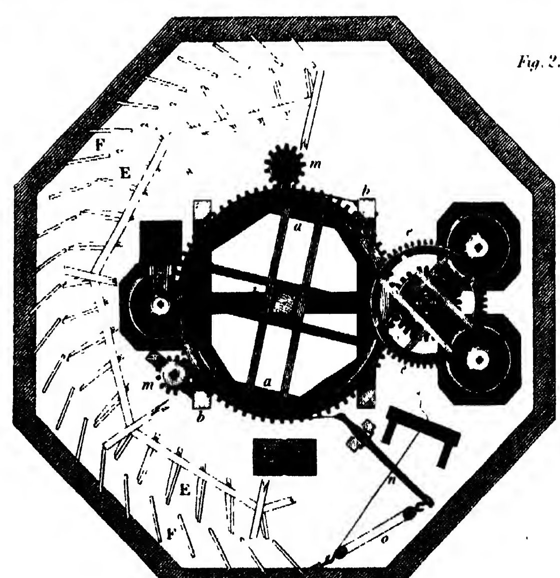


Fig. 2.



y del

Published as the Act directs, 1816, by Longman, Hurst, Rees, Orme, & Brown, Paternoster Row, London.

Lowry sculp.

Wire

WIRE, in the *Mechanic Arts*, is a very ufeful preparation of different metals, in form of a regular and even thread, which can be obtained in very great lengths, and of any required fize or fhape.

Wire is made of any ductile metal, as platina, gold, filver, copper, brafs, zinc, iron, or fteel. The procefs of making

wire consists in drawing the piece of metal through a hole in a plate of steel, by which means the metal is rendered of an equal size, and either round or of any other figure corresponding with the figure of the hole in the draw-plate; the metal is thus reduced in size, and at the same time is lengthened in proportion. From the great regularity of wire, and from its toughness and ductility, it is extremely useful to all artists who work in metal.

The operation is called wire-drawing, and the plate of steel a draw-plate. The machine by which the wire is drawn is called a draw-bench.

The common draw-bench is of a simple structure. A strong plank of wood is fixed on legs, like a stool or bench, *fig.* 1. *Plate Wire.* At one end is a roller or axis, A, fixed in an horizontal position, so that it can be turned round by means of four levers, B B, fixed like radii on the end of the axis of the roller. If the resistance is great, the workman applies both his hands and his feet to the levers, to turn them round in the same manner as for a rolling-press. It is usual to have a strong strap, or chain, C, to wrap and wind up round the roller; and at the end of it a pair of pincers, D, are linked: these take hold of the end of the piece of metal, and draw it through the hole in the draw-plate E, which is lodged against two strong iron pins, *a a*, fixed in the bench, and standing up perpendicularly, so that the plate bears against them.

The pincers are shewn in *fig.* 2. They are adapted to bite the end of the wire; and the inside of the jaws, *d d*, are cut with teeth like a file, that they may hold the metal very tight. The opposite ends of the handles are bent in form of hooks at *e e*; and a triangular link of iron *f*, which is fastened to the end of the strap or chain C, embraces both hooks *e e*, and from its triangular figure, it tends to approach the two hooks at the ends of the tongs together: by these means, the strain of drawing the wire closes the pincers, and makes them bite more forcibly in proportion as the wire makes a greater resistance, so that they rarely let the wire slip.

The draw-plate, *figs.* 3 and 4, is a thick plate of steel, with holes made through it of various sizes, and in a regular gradation from the largest to the smallest. The holes are made large on that side where the wire enters, and they diminish with a regular taper to the other side; the goodness of the draw-plate is an object of the first importance. The different holes must diminish by very small gradations, or there will be danger of breaking the wire by forcing it too much at once.

In some draw-benches a rack and pinion are employed, instead of a strap or chain; and a train of wheel-work may be used like that of a crane to obtain a sufficient power. (See *fig.* 5.) If the workman turns the machine by a winch or handle, it is preferable to four levers, because the motion is more regular; this is of importance for some purposes. Suppose a piece of elastic metal is forcibly drawn through a hole in a plate with a tolerably quick motion, it will be compressed at the moment of passing through the hole; but after it quits the hole, the metal will expand a little. When it is drawn very slowly, this effect will not take place; for if the compression is continued long enough it becomes permanent: hence, if a piece of large wire be drawn with an irregular motion, first quicker, and then slower, it will be sensibly larger at all the parts which pass quickly through the hole, and smaller where it is drawn slowly: if the motion is suspended for a few seconds, that part of the wire which remains in the hole will have a ring or indentation round it. This is most obvious in drawing hollow tubes, or copper-wire, which is plated over with gold or silver.

In the machine which is used for drawing strong pieces of metal, and for the very largest, the roller is usually placed in a vertical position, like a capstan, with four levers, at which several men push, whilst they walk round in a circle to turn the capstan, and wind up the chain which draws the wire through the draw-plate.

A powerful machine of this kind is described in our article PIPES, for drawing lead-pipe through a steel plate.

We have seen a very powerful wire-drawing machine used for forming large hollow tubes of brass or copper, on which the power to draw the tube was obtained by a screw, like that of a press. This screw was turned by a train of wheel-work, with a fly-wheel to regulate the motion.

Another plan, which is perhaps the best mode for a very powerful drawing-machine, is to apply the force of the hydrostatic machine originally invented by Pascal, and revived by the late Mr. Bramah. (See MACHINE, and PRESS.) By this means, very large wires for piston-rods of steam-engines, and other similar pieces, may be rendered straight and true with little expence.

All these machines are confined to draw pieces of metal, which are only a few feet in length, that is, the length of the bench. But when the metal by repeated drawing becomes lengthened into a regular wire, if it is required to reduce it to a still smaller size, it must be drawn through succeeding plates, by wrapping the wire itself upon the roller or barrel, instead of employing a long chain. This method is not applicable at first, because a thick bar of iron could not be made to bend easily round a roller; but when the wire becomes small and flexible, it can be practised very advantageously, and admits of drawing a very great length of wire by a small and commodious machine.

The common wire-mills used in France do not, however, employ a roller or windlass, but the pincers are attached to a lever, which draws them backwards and forwards alternately by the power of the water-wheel.

The pincers are so constructed, that the jaws open when they move towards the draw-plate, and release themselves from the wire; but when the pincers are drawn back from the draw-plate, the link causes the pincers to close and bite the wire with such force, that they will draw it through the plate.

A machine of this kind is shewn in *fig.* 7. of the plate. The base of the machine is a very strong log of timber R; one end of it is cut open to receive a wooden lever A B, which moves round an iron pin or bolt *n*, as a centre of motion; this lever is shaped like the letter L. To the upright arm A of this lever, an iron link C is jointed, and the other end of this link is formed like a ring, to receive the handles of the pincers D. The pincers are supported upon a plate of iron *d*, which is placed in an inclined position, and there is a groove in the plate, into which the end of the pin or joint of the pincers is received, and they are by that means guided in their motion backwards and forwards: *a a* are the pins which support the draw-plate E; there are four of them, and the plate is fastened between them by wedges.

The end B of the lever is operated upon by cogs fixed on the axis of the water-wheel, which, as it turns round, depresses the end B of the lever; and the end A pulls the pincers back, and draws the wire through the draw-plate; but when the cogs quit the end of the lever, it is returned by means of a rope fastened to the end of B, and going up to a strong wooden pole fixed on the roof of the building; and it acts as a spring. When the pincers return, they open to release the wire, and slide down the inclined plate *d* by their own weight, till they are near the draw-plate; the wire being all the time included between the jaws, though

they do not bite. The next cog which feizes the end of the lever draws back the pincers, which immediately clofe upon the wire, and draw it through the plate.

A wire-mill ufually contains three fuch machines of different fizes: the largeft only draws two inches of the wire at each ftroke, and makes about forty eight ftrokes in a minute; the fecond machine, four inches; and the third, five inches. This works quicker than the other two, and makes fixty-four ftrokes per minute. This is a fimple machine, but very defective, for much time is loft in the returning of the pincers; they fometimes fail to take good hold of the wire, and they always make deep marks upon the wire at every place where they bite, which are not more than two inches diftance in the great wire, and five inches in the fmaller.

Fine wire is always made from large wire, by reducing it and lengthening it out by repeated drawings. The large wire is ufually manufactured at the wire-mills in the country, and fome part of it is reduced to fmall wire at the fame eftablifhments, but more commonly the large wire is bought by thofe who have occafion for it, and they reduce it by drawing until it becomes as fmall as it is wanted.

The hand-machine for this purpofe, reprefented in *fig.* 8, is extremely fimple. A is the roller on which the wire is wound up; it turns round upon a vertical pin, fixed in the bench R, and to the upper end a handle B is fixed, for the workman to turn it round; E is the draw-plate, and *a a* the pins againft which it refts. The wire which is to be drawn is put upon a fmall circular reel F, which turns round upon a vertical pin; this pin is fometimes fixed in the table, or otherwife in a fmall cafk containing ftarch-water, or beer which has become acid. The ufe of this is to loofen the oxyd from the furface of the wire, for it is neceffary to anneal or foften the wire very frequently, by putting it in the fire, and this produces a black coat of oxyd on the furface, which will be removed when the wire is again drawn through the plate, and the wire will come out bright and clean. The removal of this oxyd will be facilitated by fome flightly corrofive menftruum.

Fig. 9. is a very fimple and complete wire-drawing machine, to draw three wires at once. A R are two rollers or barrels with cog-wheels, T V, on the ends of their axis, which wheels are engaged together. S is a pinion, which is turned round by means of a handle B, and gives motion to the wheels T V. Both thefe wheels are fitted upon round parts of the axis of their refpective rollers, fo as to flip or turn freely round upon the fame; but a fquare is formed on the axis outfide of the wheel, and a clutch or catch, *t* or *v*, is fitted on this fquare part, fo as to turn always round with the axis. The catch is at liberty to flide upon the axis in the direction of its length, by means of a lever W, which operates upon both catches at once. When either of them is pufhed back in contact with the wheel, it intercepts two ftuds which project from the face of the wheel, and then compels the axis and roller to turn round with the wheel; but when the catch is drawn away from the wheel, then the wheel will flap round upon its axis, without communicating any motion. By means of the lever W, only one wheel can be engaged at once, and the other muft be free. The draw-plate E is firmly fixed between the two rollers, and it has a great many holes; the rollers are long enough to receive three wires at the fame time. Each roller has a groove in it parallel to the axis, into which a bar of metal is fitted, and will exactly fill it up. When the wires are introduced through the holes in the plate, the ends are laid acrofs this groove; the bar is then put in and faftened by a fimple contrivance, and it faftens the ends of the wires beneath it, fo that they become attached to the roller; then by turning the handle B round, the two wheels are put in motion in contrary directions; and that wheel which is connected with its axle by its catch, will turn its barrel round, and wind up the wires fo as to draw them through the plate E. The other roller being at the fame time detached, its wheel is at liberty to turn round in a contrary direction to the wheel, as faft as the wires are drawn off from it. When the whole length of the wires has been drawn through the plate, they are detached from the roller, the ends introduced through fmaller holes in the plate, and faftened again to the roller; then the lever W is fhifted, to difengage that wheel which operated before, and engage the other. This being done, the rollers will be turned in an oppofite direction, and will wind back the wires, although the handle B is turned the fame way round.

After the wire has been then drawn three or four times, the metal becomes fo hard and fibrous, that it would not draw any more without breaking; it therefore requires to be heated in the fire to reftore its ductility; for this purpofe it muft be taken off the barrels. A roller M is provided to wind the wire upon and draw it off from the barrel; this roller is turned round by a handle *m*, fixed on the extremity of its axis; and the wire which is wound upon it in a coil is flipped off fideways. This machine is well adapted to be worked by a mill, becaufe the handle may always be turned the fame way.

Fig. 10. reprefents the machine ufed at the wire-mills for reducing the wire which is to be ufed for mufical inftruments, or for making cards for wool and cotton. The rollers A are fituated in a vertical pofition, being fitted on the tops of iron fpindles, which are fuftained in a vertical pofition by bearings in the frame of the table or bench. Thefe fpindles are kept in continual motion by wheel-work fituated beneath the bench, but the fpindles are round, fo that the rollers A are not turned with the fpindles, unlefs any one of the rollers is lifted up upon the fpindle. A crofs-bar, which is fixed on the top of the fpindle, then engages with two projecting knobs fixed in the roller, within a hollow recefs made at the top of it, and turns the roller round. The draw-plate E is fupported by two pins, as before defcribed; and the wire which is to be drawn is wound on a reel, which is put into a cafk of ftale-beer grounds, or ftarch-water. The end of the wire, which is put through the draw-plate, is made faft to the roller, which does not turn round as long as it is dropped down upon the fpindle; but when all is ready to begin drawing, the roller muft be lifted up, and the clutch at the top of the fpindle will engage with the two knobs within the hollow at the top of the roller. This puts it in motion, and draws the wire through the draw-plate. The ftrain of drawing is fufficient to keep the roller up upon the fpindle; but as foon as the whole of the wire is drawn through the plate, the refiftance ceafes, and the roller drops down on its fpindle, and becomes difengaged until the workman puts it again in action.

Manufacture of Iron Wire.—Iron is a very ductile metal, but requires a careful treatment in the procefs of wire-drawing, becaufe it becomes very hard and brittle when the fibres are greatly compreffed by repeated drawing. Its ductility muft then be reftored by heating the wire to rednefs; this is called annealing: it renders the wire foft, and it will then draw finer and longer; but it will foon require annealing again, and fo on.

The iron which is felected for wire-drawing muft be of good quality, to bear the requifite extenfion without breaking. It muft be of an uniform fubftance, without any grains

of hard or soft parts. The softest iron is not always found the best, as it will diminish by the strain of drawing it through the holes alone: and to obviate this, the workman must draw such iron through a greater number of holes to obtain the required extension.

The iron is wrought at the tilt-mills from square bars into round rods of a proper size to commence drawing. The operation of tilting is nearly the same as *tilting of steel*. (See that article.) The tilt-hammer for a wire-work generally makes twenty strokes *per* minute, and weighs about fifty pounds. There is also a larger hammer worked by the same mill, which strikes about 130 times *per* minute, and weighs 100 pounds. This hammer is only used for the first preparation of the iron, or for welding a faggot of small bars together, in order to give the iron a better quality by a preparation similar to the German steel. To draw out the iron bars into rods of a proper size to begin drawing, the workman heats six or eight inches of the end of a large bar, which comes from the great forge where the iron is made, and when properly heated he works it regularly under the small tilt, until it is drawn out to a small and regular round rod of five or six feet in length. A good workman can thus draw out two hundred weight of iron in a day, or an ordinary workman one and a half hundred weight. The loss of metal in the operation is near 26 *per cent.* by weight.

The small rod, before it is cold, is taken by another workman, who straightens the rod with a hammer upon an anvil, then cuts it off, and places the end of the great bar again in the forge. This same workman also superintends the heating of the iron, and must be very careful not to overheat it, but to heat the whole regularly.

It is a good practice to pass the iron-rod through a pair of grooved rollers, the grooves of the two rollers being opposite, so as to form a round between them. By these means, the iron may be reduced small, and rendered very true, previously to beginning the drawing. For common wire, the whole reduction may be done by the rolling-mill without a tilt; but the hammer will give a more tenacious quality to the iron than can be obtained by rolling.

A small round bar, thus prepared, must be drawn through a hole in a draw-plate, by a strong machine with a chain, or else by the lever-machine, *fig.* 7. The end of the iron is first reduced, so that it will enter the hole in the draw-plate, and pass through sufficiently for the pincers to take hold. This is done at the forge by a hammer and anvil. By passing through the plate the wire becomes lengthened, in proportion as it is diminished in size. It must then be annealed to soften it, the end pointed anew, and again put through a smaller hole.

The workman who attends the process must study the nature of the iron, and regulate the manner of drawing accordingly. This he does by altering the figure of the hole through which the wire is drawn. The hole must be conical; the smallest part, being that which acts principally on the metal, must be at that side of the plate where the wire comes through. If the taper of the hole is not properly proportioned, the iron will be strained in drawing; for though the machine will force it through, grains of harder metal than the rest of the wire will form themselves, which will occasion the wire to break when it comes to be much reduced. This is particularly the case in soft iron. To avoid this, the hole must be chosen very little smaller than the iron, and must be made with a regular taper. It must be well supplied with grease, to diminish as much as possible the friction; and the motion of the draught must be regulated according as the metal will bear it.

Much depends upon the quality of the draw-plate; although the metal of the plate is sufficiently hard to draw the wire, it will not resist the blow of a hard steel hammer and punch. The punch is driven into the hole from behind, until it enlarges it to the required size and figure. In the operation of drawing, the hole becomes gradually enlarged, and that in a greater degree at the smallest end of the hole, so that it becomes nearer to a cylinder. To rectify this, the punch must be applied, or the wire would not pass easily; that is, if the same degree of reduction in the size of the wire was attempted, it would break or strain the wire, if the hole was cylindrical, although it would pass through a regular taper hole. The hole sometimes wears irregularly, and loses its circular figure. In this case, the plate is hammered around the small end of the hole, and the hole is thereby reduced. The punch is then driven in, to enlarge it again to the required size: sometimes the punch is introduced at the small end, and then at the large end, as it may be required to form the hole. In all cases, the punch must be driven very gently; and after every stroke of the hammer it must be loosened in the hole, and turned round before another blow is struck, and without this precaution it would fix fast in the hole.

The French draw-plates are the most esteemed; and, in time of war, a good French draw-plate has been sold for its weight in silver. M. Du Hamel, in Les Arts et Metiers, vol. xv. gives the following account of the process of making the draw-plates for the large iron-wire.

A band of iron is forged of two inches broad and one inch thick. This is prepared at the great forge. About a foot in length is cut off, and heated to redness in a fire of charcoal. It is then beaten on one side with a hammer, so as to work all the surface into furrows or grooves, in order that it may retain the substance called the potin, which is to be welded upon one side of the iron, to form the hard matter on which the holes are to be pierced. This potin is nothing but fragments of old cast-iron pots; but those pots which have been worn out by the continued action of fire are not good: the fragments of a new pot which has not been on the fire are better.

The workman breaks these pieces of pots on his anvil, and mixes the pieces with charcoal of white wood. He puts this in the forge, and heats it till it is melted into a sort of paste; and to purify it he repeats the fusion ten or twelve times, and each time he takes it with the tongs to dip it in water. M. Du Hamel says, this is to render the matter more easy to break into pieces.

By these repeated fusions with charcoal, the cast iron is changed, and its qualities approach those of steel, but far from becoming brittle; it will yield to the blows of the hammer and to the punch, which is used to enlarge the holes. The bar of iron which is to make the draw-plate is covered with a layer of pieces of the potin, or cast iron, thus prepared. It is applied on the side which is furrowed, and should occupy about half an inch in thickness. The whole is then wrapped up in a coarse cloth, which has been dipped in clay and water mixed up as thick as cream, and is put into the forge. The potin is more fusible than the forged iron, so that it will melt. The plate is withdrawn from the fire occasionally, and hammered very gently upon the potin, to weld and in some measure amalgamate it with the iron, which cannot be done at once; but it must be repeatedly heated, and worked until the potin fixes to the iron. The workman then throws dry powdered clay upon it, in order, they say, to soften the potin.

The union being complete, the plate is again heated, and forged by two workmen, who draw out the plate of one

foot to a length of two feet, and give it the form it is to have. It is well known that cast iron cannot be worked at the forge without breaking under the hammer; but in the present instance, it is alloyed with the iron-bar, and is drawn out with it. It has also acquired new properties by the repeated fusions with charcoal.

The holes are next pierced whilst the plate is hot. This is done with a well-pointed punch of German steel, applied on that side of the plate which is the iron-bar. It requires four heats in the fire to pierce the holes, and every turn a finer punch is employed, so as to make a taper hole. The makers of draw-plates do not pierce the holes quite through, but leave it to the wire-drawers to do it themselves when the plate is cold, with sharp punches, and then they open the hole to the size they desire; and although this potin is of a very hard substance, the size of the hole may be reduced by gentle blows with a hard hammer, on the flat surface of the plate, round the hole.

A great many holes are made in the same plate; and it is important that they should diminish in size by very imperceptible gradations; so that the workman can always choose a hole suitable for the wire he is to draw, without being obliged to reduce it too much at once.

To ascertain the size of the wire, gauges are used. They are commonly made of a piece of wire bent in zigzag, as shewn in *fig.* 11; and the space between every bend is of a different width; but a better sort is made of a steel-plate, with notches on the edge. (See *fig.* 12. for the standards.) These should be hardened, that they may not be subject to wear.

Fig. 13. is another kind of gauge, which is very accurate. It consists of two straight rules of steel, put together at an angle. The diameter of the wire is indicated by the depth to which it will enter into the angle; the edges of the rulers are divided into equal parts for that purpose, and numbered, to correspond with the different sizes of wire.

The wire manufactory of Messrs. Mouchel, situated at l'Aigle, in the department de l'Orne, is one of the most considerable in France. It furnishes annually, in cards for wool-combing only, an hundred thousand quintals of iron-wire, each 100lbs. A part of this is consumed in France, and the rest is exported to Portugal, Spain, Italy, and even to the shores of the Levant.

They employ the iron manufactured in the departments of l'Orne and La Haute Saone, as being of the best quality. The first produces the best wire for making screws, nails, and pins, as much on account of its hardness as its fine polish, which resembles steel-wire. In this respect, it is superior to the iron of Haute Saone, but from its ductility the latter can now be made extremely fine, and it appears to be most free from heterogeneous particles.

The smelted iron, prepared and hammered, being in a state nearly fit for their purpose, is transported, at a small expence, to l'Aigle, by the rivers and canals. They have a forge to reduce the steel and iron of Normandy, which arrives in large pieces, into small and regular bars.

When the iron is formed into an irregular bar of about a centimetre, near four-tenths of an inch in diameter, they begin to draw it into wire. Although it be already much extended by hammering, it is in the first place passed four times through the drawing-plate; then its molecules become disposed lengthways, and exhibit fibres at their utmost extension. The fibres must be removed by means of heat, which disperses and divides them; and after that the wire may again be reduced three numbers. The fibres which are re-produced by this operation are again removed by heat. The whole process is five times repeated; consequently the wire is passed through fifteen numbers; after which, a single exposure to the fire is sufficient to fit it for passing six others, whereby it is reduced to the thickness of a knitting-needle.

The steel-wire, being much harder, requires to be passed through forty-four numbers, and to be annealed every other time.

The machine which draws the steel-wire must go slower than that which draws the iron; for the first being very hard, and offering more resistance to the drawing-plate, should be pulled out with more care, since the quickness ought to be proportioned to the resistance, and reciprocally; and if they depart from this principle, the results will vary. Thus, for example, the iron of the department de l'Orne, which is more compact than that produced at Haute Saone, if drawn by the same machines, augments in hardness, and is weakened when it is brought to too great a degree of fineness. But this iron, which is very hard, and capable of receiving a very high polish, is to be preferred for certain uses.

In order to anneal the wire, they formerly employed a large and elevated furnace, with bars of cast iron to support the wire in the middle of the flames. It contains seven thousand pounds weight, so contrived as to contain equal portions of each number. They are so arranged that the thickest wires receive the strongest heat; therefore, the whole is equally heated in the same space of time. The operation lasts three hours with a fire well kept up, and it might be imagined that this apparatus was completely adapted to the purpose; but there are imperfections in this method, because it leaves the wire exposed to the contact of the atmospheric air, the oxygen of which seizes it with extreme avidity; whence a considerable quantity of oxyd is occasioned, and also an operation to free it from the scales, which consists of beating the bundles of wire with a wooden hammer wetted with water.

Notwithstanding this precaution, there often remains a portion of oxyd adhering to the surface of the metal, which streaks the draw-plate, or fixes on the wire, and gives it a tarnished appearance, and causes it to break when it is brought to a great degree of fineness. This furnace is only used for the steel-wire, or the iron from l'Orne, which is less liable to change, and besides being harder is not so easily attacked by the oxygen.

In order to diminish the waste that the fire occasions, they have contrived another process, which consists in dipping the bundles of wire into a basin of wet clay before they put them into the furnace; and they are left in the furnace to dry before the fire is lighted, without which precaution the clay would peel off from the iron.

For making wire for cards, M. Mouchel invented another furnace. It is round, and about one metre six decimetres in diameter, and one metre eight decimetres in height, without including its parabolic arch and the chimney above it. The interior is divided by horizontal grates into three stories; the lowest receives the cinders, the second is the fire-place, and into the third or upper place they slide a roleau of wire, weighing one hundred and fifty kilogrammes, which is inclosed in a space comprised between two cast-iron cylinders, being luted to prevent the admission of air between them. The flames circulate about the outside of the first, and within the interior of the second, which defends the wire from atmospheric air. The diameter of the largest cylinder is about one metre four decimetres, that of the second one metre. Thus the space comprised between them is two decimetres, on an elevation of five decimetres. There must be several pairs of cylinders provided; because whilst one

pair is in the furnace another muſt be prepared to receive a freſh roleau of wire. They are changed every hour by means of a long iron lever, with which a ſingle man can eaſily puſh them in and draw them out again, as the cylinder ſlides on caſt-iron rails.

They are very careful not to open the cylinders immediately on their being drawn out of the fire; for the roleaus of wire contained in them, being ſtill red, would oxydate quite as much as if they had been heated in the midſt of the flames without the leaſt precaution.

The opening contrived for the paſſage is on the ſide, and has a door of caſt iron, with a groove which winds round the furnace. The fire-place has one ſomething ſimilar to it. That of the aſh-hole is vertical, in order that it may be raiſed to increaſe the fire at will.

When the iron-wire is reduced to the thickneſs of a knitting-needle, it is made up in bundles of 125 kilogrammes (275 pounds) each, into a large iron veſſel, in order to anneal it ſufficiently to be reduced for the laſt time. This veſſel is placed upſide-down in the middle of a round furnace, which is ſo conſtructed as to ſuſtain burning coals all round it, and of which it conſumes 35 kilogrammes (77 pounds) before the operation is completed. The cover muſt be carefully luted, as the ſlighteſt admiſſion of air is ſufficient to burn the external ſurfaces of the wire to an oxyd, which cannot afterwards be reduced.

When one of theſe veſſels is ſufficiently heated, it is filled with water, containing three kilogrammes (ſix pounds and a half) of tartar, and ſuſpended over the flames of the furnace to make it boil. This ſolution, without attacking the metal, frees it from the greaſe and the little oxyd that adheres to it. This is the laſt operation in which the wire is expoſed to the fire; and it is then in the proper ſtate for being reduced to the utmoſt degree of fineneſs it is capable of ſuſtaining, and will preſerve enough of the effect of the annealing to require it no more. But when the natural hardneſs of the iron varies, this laſt expoſure to the fire ſhould take place in proportion to its thickneſs. As ſteel loſes its capacity of extenſion much ſooner than iron, it is annealed until it is no thicker than a ſewing-needle. The ſpace which is left in the veſſel is filled up with charcoal-duſt, which prevents it from loſing the quality of ſteel, and preſerves the heat long enough to give it the proper degree of pliancy.

As Meſſrs. Mouchel always uſe iron and ſteel of the ſame manufactory, they have been able to reduce their operations to a general ſyſtem; and to attain this end, have determined a graduated ſcale, by which the wire will not be more ſtretched in the drawing-plate in one number or ſize than another. The following is the method they contrived, in order to form this ſcale for the iron-wire. They take a certain quantity of various thickneſſes, which has been drawn as fine as the iron would bear. The ſmalleſt ſize is 100,000 metres (109,333 yards) in length to the kilogramme, 2.2 pounds avoirdupois. They note the weight that each might be capable of ſupporting without breaking. This being expreſſed by figures, it is eaſy, by a few interpolations, to expreſs them in a progreſſive form. This kind of ſcale has been partly formed by comparing the weight of the different ſizes with equal lengths, from which gauges or calibres may be made for the uſe of the workmen. Theſe gauges are certain guides, which they cannot miſtake except through great careleſſneſs. If they had not theſe guides they would often paſs the wire through holes in the drawing-plate that are too large for it, whence it does not acquire the ſtrength it ſhould have in proportion to its thickneſs, and loſes its hardneſs. They might alſo paſs it through holes that were too ſmall, which would weaken it, and render it very brittle. In the latter caſe, it frequently happens that the ſteel of the drawing-plate, being unable to ſuſtain the force to which it is expoſed, will give way, as if the plate were too ſoft; and the wire will be brittle at the beginning, and ſoft and too thick at the other extremity.

The greateſt part of the fine wire of Meſſrs. Mouchel's manufactory is drawn by workmen who are diſperſed about the country; but they have alſo a machine which moves twenty-four bobbins in a horizontal direction, which only requires the workman to look after it. It is upon the bobbins that the wire is reduced to the different degrees of thinneſs deſired; therefore, this is the laſt operation in the art of making iron and ſteel wire; although it has all requiſite qualities given to it in the work-ſhop of the wire-drawer.

Wire is ſtill incapable of being made into needles and carding-hooks, until it has undergone another operation for dreſſing or ſtraightening the wire, by which it is made to loſe the bend or curve that it acquires on the bobbins.

This work conſiſts in drawing the wire between nails fixed in a piece of wood, and which act to bend the wire, firſt in one direction, and then in the oppoſite, in a waving line, of which the waves are at firſt larger, but decreaſe gradually, and the laſt bend of which tends to force the wire into a ſtraight line. The dreſſer is obliged conſtantly to adjuſt the nails, by inclining or raiſing them with ſtrokes of the hammer. Alſo for each number of wires the pins muſt be at different and calculated diſtances. This requires a workman of intelligence, diligence, and addreſs.

An ingenious inſtrument is now appropriated to this operation, and removes all difficulty. Six little puppets of very hard ſteel are ſubſtituted for the nails of the ordinary inſtrument, and are fixed on parallel bars of metal, ſo jointed together that the movement of them all will be parallel, and the puppets are widened or brought nearer together by ſcrews. The wire is drawn between theſe puppets in a zigzag or waving line, and the repeated flexures break the ſinuoſities of the wire. There is a conductor of the wire to the puppets, and another conductor which ſerves to prevent the wire from being ſhaken. There are ſlight grooves at the extremity of the puppets, to give a paſſage to the wire. A ſcale ſuſtained by a ſcrew indicates the diſtance at which the puppets ſhould be placed from each other, to ſtraighten each ſize of wire. This forms an invariable rule, and the dreſſer (who may be a child) ſaves a third of the time which is employed in regulating the nails of the inſtrument formerly uſed. There is nothing more to be done but to draw out the wire by means of a wheel, on which he reels it, and then forms it into bundles to be delivered to the conſumers.

The ſteel-wire of France is proper for many purpoſes. It is brought from Meſſrs. Mouchel, for making knitting-needles in the Engliſh faſhion, ſhoemakers' needles, and other ſimilar articles. It may alſo be uſed for needles of all ſizes, and even for cards for wool-combing; but as this ſteel is much more expenſive than the iron-wire, it is very ſeldom uſed for the latter purpoſe.

The method of preparing the draw-plates is deſcribed by Meſſrs. Mouchel, and is different from that before deſcribed.

For making wire for cards, two ſorts of drawing-plates are uſed, large and ſmall ones. The firſt, for the ſort of wire that we have been deſcribing, is drawn with the pincers, as *fig.* 7, and with the bobbin or roller, which is a cylinder adapted to the axis turned by the water-mill, and is uſed in preference, to avoid the marks made on the wire by the pincers. The ſmall drawing-plates are uſed for ſuch wire

as may be drawn by hand. The ſteel which they employ for theſe drawing-plates ſhould never vary in quality, except that the ſmaller plates are made of the fineſt ſteel. Several pieces of iron are diſpoſed in the furnace in the form of a box without a lid, their weight being according to the uſe for which they are intended to be employed.

The workman fills each of theſe boxes with caſt ſteel, and having covered it over with a luting of clay, it is expoſed to a fierce fire until the ſteel be melted. His art conſiſts in ſeizing the proper moment to withdraw the plate from the fire: he raiſes the luting, and blows on it through a tube, in order to drive off all heterogeneous parts, and then amalgamates it with the iron by light blows. After it is cool, he replaces it at the fire, where the fuſion again takes place, but to a leſs degree than before; he afterwards works the ſteel with light blows of the hammer, to purify and ſolder it with the iron. This operation is repeated from ſeven to ten times, according to its quality, which renders it more or leſs difficult to manage. During this proceſs, a cruſt forms on the ſteel, which is detached from it the fifth time of its expoſure to the fire, becauſe this cruſt is compoſed of an oxydated ſteel of an inferior quality. It ſometimes happens that two and even three of theſe cruſts are formed of about two millimetres, or one-ſixteenth of an inch in thickneſs, which muſt alſo be removed.

After all theſe different fuſions, the plate is beaten by a hammer wetted with water, and the proper length, breadth, and thickneſs, are given to it. When thus prepared, the plates are heated again, in order to be pierced with holes by punches of a conical form; the operation is repeated five or ſix times, and the punches uſed each time are progreſſively ſmaller. It is of importance that the plate never be heated beyond a cherry-red, becauſe if it receives a higher degree of heat, the ſteel undergoes an unfavourable change. The plates, when finiſhed, preſent a very hard material, which neverthelеſs will yield to the ſtrokes of the punches and the hammer, which they require when the holes become too much enlarged by the frequent paſſing of the wire through them.

When the plates have been repaired ſeveral times, they acquire a degree of hardneſs, which renders it neceſſary to anneal them, eſpecially when they paſs from one ſize to another; ſometimes they do not acquire the proper quality until they have been annealed ſeveral times. Notwithſtanding all the precautions which are taken in preparing the plates, the ſteel ſtill varies a little in hardneſs, and according to this variation they ſhould be employed for drawing either ſteel or iron wire; and if the workman who proves them finds that they are too ſoft for either the ſteel or iron, they are put aſide, to be uſed by the braſs-wire drawers.

A plate that is beſt adapted for drawing ſteel-wire is often unfit for the iron; for the long pieces of this latter metal will become ſmaller at the extremity than at the beginning, becauſe the wire as it is drawn through the plate is inſenſibly heated, and the adhering parts are ſwelled, conſequently preſſed and reduced in ſize towards the latter end. The plates that are fit for braſs are often too ſoft for iron, and the effect reſulting is the reverſe of that produced by a plate that is too hard.

The ſmalleſt plates which Meſſrs. Mouchel uſe are at the leaſt two centimetres, or eight-tenths of an inch in thickneſs, ſo that the holes can be made ſufficiently deep; for when they are of a leſs thickneſs, they will ſeize the wire too ſuddenly and injure it. This inconvenience is much felt in manufactories where they continue to uſe the plates for too long a time, as they become exceedingly thin after frequent repairs. One of Meſſrs. Mouchel's large plates reduces 1400 kilogrammes (3080 pounds avoirdupois) from the largeſt ſize of wire to No. 6, which is of the thickneſs of a knitting-needle; 400 kilogrammes (880 pounds) of this number are afterwards reduced in one ſingle ſmall plate to No. 24, which is carding wire; and to finiſh them, they are paſſed through twelve times ſucceſſively.

For the tenacity of iron wire, ſee Iron.

The firſt wire-mill in England was ſet up by a Dutchman at Sheen, near Richmond, in 1663.

Wires are frequently drawn ſo fine, as to be wrought along with other threads of ſilk, wool, or hemp: and thus they become a conſiderable article in the manufactures. See Ductility.

Wire, *Gold*. See Gold-*Wire*.

Muſchenbroeck records, that an artiſt of Augſburg drew a wire of gold ſo ſlender, that 500 feet of it weighed only one grain; and Dr. Wollaſton, ſecretary of the Royal Society, has ſhewn, that a wire of gold may be drawn much finer than this, and that wires of platina may be drawn much more ſlender, with the utmoſt facility. Thoſe who draw ſilver-wire in large quantities for lace and embroidery, ſometimes begin with a rod that is about three inches in diameter, and ultimately obtain wires that are ſo ſmall as $\frac{1}{100}$ of an inch in thickneſs. If in any ſtage of this proceſs a rod of ſilver-wire be taken, and a hole be drilled through it longitudinally, having its diameter one-tenth part of that of the rod, and if a wire of pure gold be inſerted, ſo as to fill the hole, it is evident that by continuing to draw the rod, the gold within it will be reduced in diameter exactly in the ſame proportion as the ſilver; ſo that if both be thus drawn out together till the diameter of the ſilver is $\frac{1}{500}$ of an inch, then that of the gold will be only $\frac{1}{5000}$; and of ſuch wire, 550 feet would be requiſite to weigh one grain. In order to remove the coating of ſilver that ſurrounds it, the wire muſt be ſteeped for a few minutes in warm nitrous acid, which diſſolves the ſilver without any injury to the gold. Dr. W., in his endeavours to make ſlender gold-wires by the method above-deſcribed, found it difficult to drill the central hole in a metal ſo fine as ſilver, and therefore tried whether platina might not be ſubſtituted for the gold, as in that caſe its infuſibility would allow its being coated with ſilver, without the neceſſity of drilling. Having formed a cylindrical mould one-third of an inch in diameter, he fixed in the centre of it a platina wire previouſly drawn to the $\frac{1}{100}$ of an inch, and then filled the mould with ſilver. When this rod was drawn to $\frac{1}{30}$, his platina was reduced to $\frac{1}{1000}$, and by ſucceſſive reduction he obtained wires of $\frac{1}{4000}$ and $\frac{1}{5000}$, and excellent for applying to the eye-pieces of aſtronomical inſtruments, and perhaps as fine as can be uſeful for ſuch purpoſes. The extremity of a platina wire having been fuſed into a globule near $\frac{1}{4}$ of an inch in diameter, was next hammered out into a ſquare rod, and then drawn again into a wire $\frac{1}{253}$ of an inch in diameter. The fuſion was effected by the following ſimple and eaſy method ſuggeſted by Dr.

Marcet:—A piece of wire, about ſix inches long, having been bent to an angle in the middle, one half of its length was held in the flame of a ſpirit-lamp impelled by a current of oxygen, and its extremity was thus fuſed in about half a minute. An inch of the wire above-mentioned duly coated with ſilver was drawn, till its length was extended to 182 inches; conſequently the proportional diminution of the diameter of the platina will be expreſſed by the ſquare root of 182, ſo that its meaſure had become $\frac{1}{253 \times 13.5} = \frac{1}{3425}$. The ſpecific gravity of the coated wire was aſſumed to be 10.5, and ſince the weight of 100 inches was 114 grains, its diameter was inferred to be $\frac{1}{42.8}$ of an inch, and juſt eighty times of the platina thus contained in it. With portions of the platina wire thus obtained, and ſucceſſively reduced in diameter, its tenacity was aſcertained; and the reſults of ſeveral trials ſhewed in general, that the proceſs of wire-drawing, which is known to improve the ſtrength of metals within moderate limits, continued alſo to add ſomething to the tenacity of platina, even as far as $\frac{1}{18.000}$ of an inch, which ſupported $1\frac{1}{3}$ grain before it broke; but the wire in which the experiments were made began then to be impaired by repetition of the operation; ſo that although he afterwards obtained portions of it as ſmall as $\frac{}{30.000}$ of an inch in diameter, it was in many places interrupted, and he could not rely on any trials of its tenacity. For other particulars with regard to theſe fine wires, we refer to the Phil. Tranſ. vol. ciii. pt. 1.

Wire, *Silver*, is the ſame with gold wire, except that the latter is gilt, or covered with gold, and the other is not. There are alſo counterfeit gold and ſilver wires: the firſt made of a cylinder of copper, ſilvered over, then covered with gold; and the ſecond of a like cylinder of copper ſilvered over, and drawn through the iron, after the ſame manner as gold and ſilver wire.

By 43 Geo. III. c. 68. ſeveral duties are impoſed on wire imported, as ſet forth in tables annexed to the act; and by c. 69. ſched. A. duties are laid upon wire made in Great Britain; and by 49 Geo. III. c. 98. new duties are impoſed. Every wire-drawer who ſhall draw any gilt or ſilver wire, commonly called 'big wire,' ſhall take out a licence, for which he ſhall pay 2*l.*, to be renewed annually on pain of 20*l.* 24 Geo. III. c. 41. One licence ſuffices for a partnerſhip. Notice is to be given of working on pain of 20*l.*, and the place of working is to be approved by the commiſſioners under the ſame penalty. Wire, and bars for making it, and utenſils, found in any private workhouſe, of which no notice hath been given, ſhall be forfeited. Officers ſhall be permitted to enter and ſurvey, and the penalty of obſtructing him is 20*l.* 10 Ann. c. 26. Preventing him from taking a juſt account incurs a forfeiture of 100*l.* 26 Geo. III. c. 77. Juſt ſcales and weights ſhall be kept on pain of 10*l.* Perſons uſing falſe ſcales and weights forfeit 100*l.* 10 Geo. III. c. 44. And the ſame ſhall be forfeited and ſeized. 28 Geo. III. c. 37. Ingots or bars of ſilver, deſigned for gilt wire, ſhall be weighed in the preſence of the exciſe officer, before they be covered with gold, and again weighed and marked after the gold is laid on, under penalty of 20*l.* 15 Geo. II. c. 20.

By 10 Ann. c. 26. an allowance of one-fifth is made for waſte in reducing the big wire to ſmall wire. Removing wire before it is ſurveyed incurs a penalty of 40*l.*; and unſurveyed wire is to be kept ſeparate, on pain of 10*l.*; and the puniſhment of concealing wire, &c. is a forfeiture of 20*l.* The wire made ſhall be entered every month, on oath, on pain of 100*l.* The duty muſt be cleared off in ſix weeks after entry, on pain of double duty.

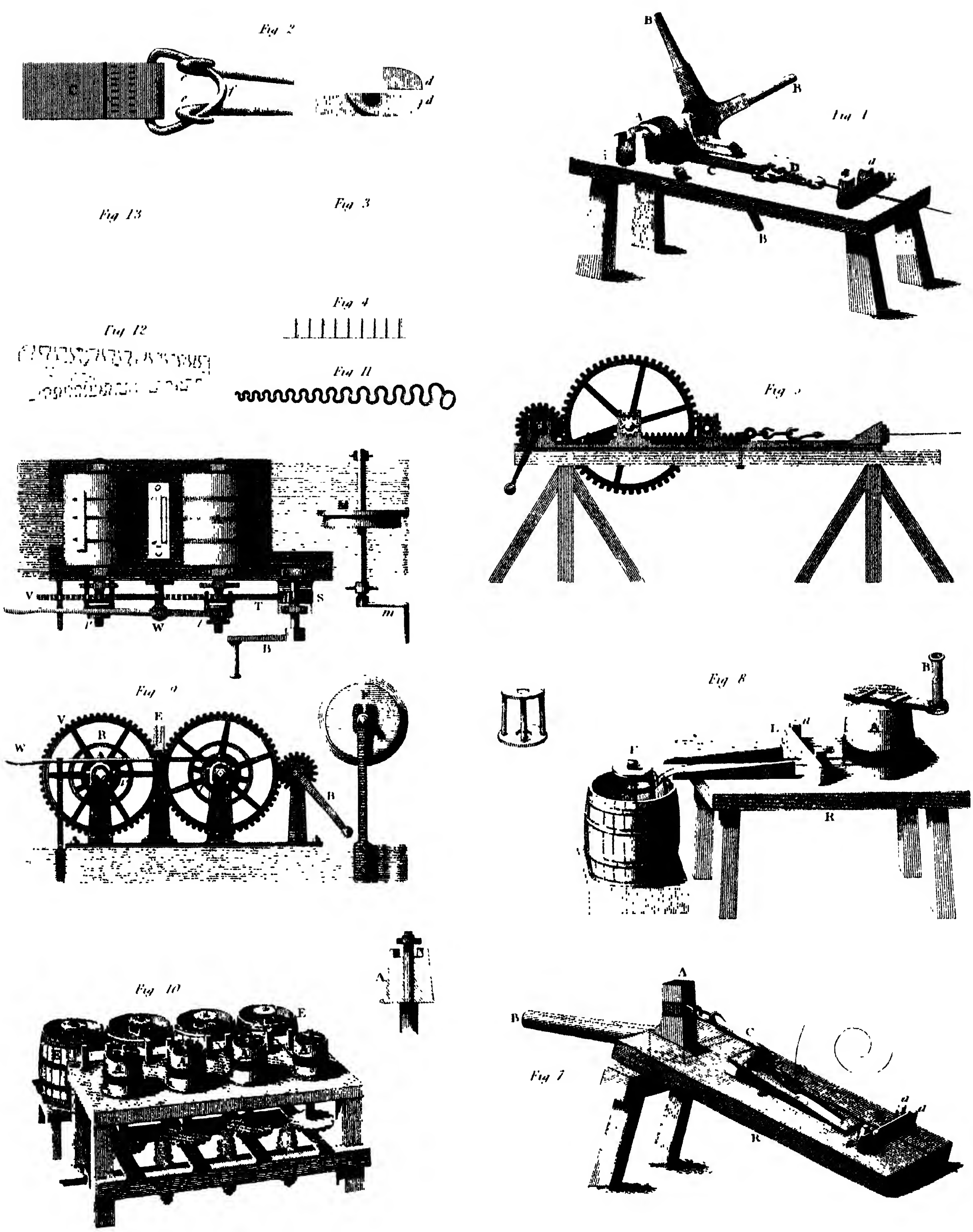
By 15 Geo. II. c. 20. and 22 Geo. II. c. 36. no foreign embroidery, or gold or ſilver brocade, thread, lace, fringe, or work made thereof, or of copper, braſs, or other inferior metal, or gold or ſilver wire, or plate, ſhall be imported. And by 10 Ann. c. 26. if any perſon ſhall export any gold or ſilver thread, or lace or fringe made of plate wire ſpun upon ſilk, he ſhall have a drawback after the rate of 5*s.* a pound avoirdupois, of ſuch ſilver thread, lace, or fringe, and of 6*s.* 8*d.* a pound of ſuch gold thread, lace, or fringe.

For regulations concerning the true making of gilt and ſilver wire, ſee the ſtatute 15 Geo. II. c. 20. and for prohibiting the ſelling or working up of foreign gold or ſilver lace or thread, ſee 22 Geo. II. c. 36.

Wire, *Braſs*, is drawn after the ſame manner as the former. Of this there are divers ſizes, ſuited to the divers kinds of works. The fineſt is uſed for the ſtrings of muſical inſtruments, as ſpinets, harpſichords, manichords, &c.

The pin-makers likewiſe uſe vaſt quantities of wire of ſeveral ſizes, to make their pins of. See Pin.

Wire, *Iron*. See Wire *ſupra*.



Farey delin
Published as the Act directs, 1820, by Longman, Hurst Rees Orme & Brown, Paternoster Row
Lowry sc

Woad

WOAD, in *Agriculture*, a plant cultivated in the field for the ufe of the dyers. It is a plant which has a ftrong thickifh fibrous root, which penetrates deep into the foil, and which is principally raifed for the ufe of the leaves, which, after being properly manufactured, are made ufe of in the art of dyeing to produce a blue colour, as well as the bafis of black, and fome others.

Soil.—It is evident from the nature of its root that it requires a foil which has much depth or ftaple, and which is perfectly frefh, fuch as thofe of the rich, mellow, loamy, and deep vegetable kind. Where this fort of culture is carried to a confiderable degree of perfection, as in Lincolnfhire, the deep, rich, putrid, alluvial foils on the flat tracts extending upon the borders of the different large rivers are chiefly employed for the growth of this fort of crop; and it has been fhewn by repeated trials that it anfwers moft perfectly when they are broken up from a ftate of fward immediately for it. In fome places, it is the practice to take lands of this defcription at high prices, for the purpofe of breaking them up and growing it upon them for two or three years; on the more low rich foils, for four years, but on thofe of lefs fertility only for three; and in fome, which are more elevated and expofed, two are confidered fufficient. For this fort of culture, people are employed, who move from place to place, and form a fort of colony. Mr. Cartwright, in the above county, has however found, that it is capable of being confined to one fpot with equal or greater fuccefs, by having a fufficient extent of ground for changing the place of its growth as may be neceffary, and for appropriating an adequate proportion annually to the raifing of the plant, by which the houfes and expenfive machinery that are neceffary for its preparation may be kept conftantly and regularly employed in the bufinefs.

Preparation.—In order to prepare the land for this crop, it is advifed by fome to plough it up with a good deep furrow, immediately before the winter commences, laying it in high narrow ridges, to have the full effect of the frofts; and early in the fpring to give another ploughing in the contrary direction, leaving the ground in the fame kind of ridge as before. When it has remained in this ftate fome length of time, and weeds appear, it fhould be well harrowed down with a heavy harrow, repeating the operation fo as to render it perfectly fine and clean. About the beginning of June a third ploughing fhould be given to the full depth with a narrow furrow, and the land be afterwards well harrowed down as before; the fourth or final ploughing being given towards the beginning of July, in a light manner, leaving the furface as even as poffible for the feed. But fome take much lefs trouble in the bufinefs of prepara-

tion. In cafes where the foils are fufficiently dry, only breaking them up early in the month of February; and where the contrary is the cafe, deferring it to a later period, taking care to plough the land in a perfect manner to the depth of five inches, or more: and that the furrow-flices may be well turned, laid flat, and nicely jointed, a perfon is employed with a fpade for the purpofe of adjufting them. This prevents the graffy matters from rifing in the feams. When this has been done, the furface is repeatedly harrowed over, to raife a fufficient depth of good mould for the drill to work in; and before the feed is put in a roller is paffed over the land.

It is probable, however, that this method is inferior to the former, as the land is not brought nearly to fo fine a ftate of mould, or the graffy material fo effectually covered and deftroyed, from which injury may be done to the woad plants in their early growth.

But a method which is equally effectual with the firft, more expeditious, and which has a fuperiority over it, in more completely deftroying grubs, infects, and other vermin, which are apt to feed on the plants in their early growth, is that of paring and burning. This is, however, chiefly practifed where the fward is rough, and abounds with rufhes, fedge, and other plants of the coarfe kind, but might be had recourfe to on others, with vaft benefit.

Where the latter modes are made ufe of as foon as the feed has been put in, the land fhould be carefully drained by forming grips in fuitable directions, as wherever water ftagnates, the woad plants are liable to be injured or deftroyed.

Seed.—In refpect to the feed, it fhould be collected from ground that has been left covered with the beft plants from the preceding feafon, as they only run up to ftem and form feeds in the fecond year; and in order to have good feed, the leaves fhould not be cropped at all or but once, the ftems being fuffered to remain till the feeds in the hufks become perfectly ripened; which is fhewn by their attaining a brownifh-yellow colour, and the pods having a dark blackifh appearance. It fhould then be gathered as foon as poffible, by reaping the ftems in the manner of grain, and then fpreading them in rows thinly upon the ground if the weather be fine, when in the courfe of a few days they will be in a ftate to be threfhed out from the hufks or pods. When they are fuffered to remain too long, the pods are liable to open, and fhed the feed. Although the pod in which the feeds are contained is of a large fize, the feeds are lefs than thofe of the turnip. New feed, where it can be procured, fhould always be fown in preference to fuch as has been kept for fome time; but when of the latter kind, it fhould be fteeped for fome time before it is put into the ground.

In regard to the quantity of feed which is neceffary, it muft be regulated by the foil, and the manner in which it is fown. Where the drill is employed, lefs will be required than in the broad-caft method. It has been found that a rood of land, where the crop is good, will in general afford feed fufficient for eight or ten acres; and in fome cafes, in the broad-caft method, five or fix bufhels are made ufe of to the acre. In Kent they ufe ten or twelve pounds to the acre.

Sowing.—The time of fowing crops of this nature muft be regulated, in fome degree, by the mode of preparation that has been employed. Where the firft of the above methods has been followed, it will be much later than in the other cafes. But early fowing is in general to be preferred, as there will be lefs danger of the plants being injured by the attacks of the fly or grub. Where the weather is fuitable, and the land in a proper ftate of preparation, the feed may be fown in the latter end of February or March, continuing the fowings, in different portions of land, till about the middle of May, at fuitable intervals of time to vary the times of cropping the leaves of the plants. The late fowings are commonly executed about the latter end of July, or early in the following month at the fartheft.

With refpect to the manner in which the feed is fown, it differs according to the nature and ftate of preparation of the land. Where it is in a fine ftate of mould, the drill or row method is the method moftly practifed, which is by much the beft, as by it the plants may be kept more eafily clean and free from weeds, becoming more ftrong and vigorous, from the earth being more ftirred about the plants: but where the contrary is the cafe, the broad-caft mode is generally followed; but which does not by any means admit of the plants being kept fo free from weeds, or the mould fo well ftirred about the roots of them.

Where the firft method is had recourfe to, the feed is fown by a drilling-machine, fuch as is ufed for turnips, in equidiftant rows, eight or nine inches apart, covering it in, either by means of a harrow attached to the implement, or by paffing a light common harrow over the ground afterwards, once in a place, raking off any clods that may be prefent to the fides, or into the furrows: but in the latter mode, it muft be difperfed by the hand in as equal a manner as poffible, over the whole of the land, being then harrowed in by a light harrow, fo as to leave the land in as even and level a ftate as poffible. The ground is frequently rolled afterwards, that the furface may be left as even as poffible.

In favourable feafons with good feed, the plants moftly appear in the courfe of a fortnight, when much attention fhould be paid to fee that they are not deftroyed by the turnip-fly, or the frofts in thofe of the more early fowings; as, where that is the cafe, the land fhould be immediately refown; as in fome cafes it is not uncommon to fow the greateft part of the crop two or three times over. In the very late fowings, where the crops rife thin on the ground, it is fometimes a practice to give a better plant by forming holes with a hoe in the vacant fpots, and directing feeds to be dropped into them by the hand by women or children. This is the cafe with the late fpring-fowings till the beginning of June, or a later period.

Culture while growing.—From much of the goodnefs of the woad plants depending on the luxuriance of their growth, and the thicknefs of their leaves, it is neceffary to beftow great attention in the culture of the crop while growing. It is advifed that the fpring-fown crops, as well as thofe that are fown in the latter part of the fummer, fhould have the firft hoeings given them as foon as the plants are fully diftinguifhable above the ground, as by this means the weeds will not only be prevented from retarding the vegetation of the plants, but thefe by being thinned out to greater diftances be more at liberty to advance and become vigorous in their firft or early growth, which is a matter of much confequence to the fuccefs of the crop; and fecond hoeings fhould be given in the courfe of four or five weeks afterwards, when the plants fhould be thinned out to the full diftances at which they are to ftand, which may be fix or feven inches, or more, according to the goodnefs of the foil, conftantly leaving fufficient room to prevent the plants from being in any way crowded. The work is fometimes executed in much the fame manner as for turnips, by hand-hoes; but in others by fmall fhort fpuds, ufed with one hand, while the other is employed in clearing away the weeds; the labourers, moftly women and children, kneeling while they perform the work. When this work has been done, nothing further is neceffary till the firft cropping of

the leaves has been performed, when the plants ſhould be again immediately well weeded; and after each cropping the ſame operation be had recourſe to; the extent of crop cleared in the day being, in moſt caſes, weeded before night.

With the late-ſown crops, after the ſecond weeding in October, nothing further will be requiſite till the ſpring, about the middle of April, when the work ſhould be again well executed, the mould being completely ſtirred about the roots of the plants, that they may derive the fulleſt benefit from the operation. This will be ſufficient to keep them clean till the taking of the firſt crop; after which they muſt be again weeded, and the ſame operation be had recourſe to after each cropping of the leaves, as in the above caſe.

In reſpect to the buſineſs of gathering the crops with the ſpring-ſown ones, the leaves will generally be ready to be gathered towards the latter end of June, or beginning of July, according to the nature of the ſoil, ſeaſon, and climate; but for thoſe put in at a later period in the ſummer, they are often fit to be gathered earlier. This buſineſs ſhould, however, conſtantly be executed as ſoon as the leaves are fully grown, while they retain their perfect green colour, and are highly ſucculent; as when they are let remain till they begin to turn pale, much of their goodneſs is ſaid to be expended, and they become leſs in quantity, and of an inferior quality for the purpoſes of the dyer. In favourable ſeaſons, where the ſoils are rich, the plants will often riſe to the height of eight or ten inches; but in other circumſtances they ſeldom attain more than four or five: and where the lands are well managed in the culture of the plants, they will often afford two or three gatherings, but the beſt cultivators ſeldom take more than two, which are ſometimes mixed together in the manufacturing of them. It is neceſſary that the after-croppings, when they are taken, are conſtantly kept ſeparate from the others, as they would injure the whole if blended together, and conſiderably diminiſh the value of the produce. It is ſaid that the beſt method, where a third cropping is either wholly or partially made, is to keep it ſeparate, forming it into an inferior kind of woad.

Upon an acre of land, when well managed, in favourable ſeaſons, the produce is moſtly from about a ton to a ton and a half. The price varies conſiderably; but for woad of the prime quality, it is often from twenty-five to thirty pounds the ton, and for that of an inferior quality ſix or ſeven, and ſometimes much more.

Seeding-Crops.—With ſuch parts of the crops as are reſerved for ſeed, it is a practice with ſome to crop the leaves two or three times the firſt year, and then leave the plants to run up to ſeed in the following one; but it is a better practice to only remove the ſide-leaves, as in this way the plants are leſs weakened, and the produce of the ſeed much increaſed. The plants are likewiſe ſometimes fed down by ſheep during the winter ſeaſon; but this, from its tendency to weaken them, is equally improper and prejudicial.

Preparation of for the Dyer.—The woad, after it has been gathered, undergoes ſeveral proceſſes to prepare it for the dyer; but in the improved method it is conveyed in one-horſe carts, ſo contrived as to be lifted from the axis, and, by folding doors in the bottoms, to diſcharge their contents upon the floor above the mill, on being hoiſted up to their proper ſituation: round this floor holes are formed for putting the plants down through, in order that they may drop under the grinding-wheels. The mills for this purpoſe have ſeveral wheels for grinding the plants, which have leſs diameters on one ſide than the other, and are about three feet in width, being conſtructed with iron bars for cruſhing the woad. They are wrought by horſes, or any other power, as may be the moſt convenient. The materials are preſerved under the grinding-wheels by proper contrivances, which, as ſoon as they are ſufficiently reduced, force it out of the tracks upon the ſtone floors on the ſides; thus making way for new parcels without the mill being ſtopped. The bruiſed woad is then thrown into rooms on the ſides of the mill, deſtined for its reception, by means of ſhovels. In theſe it remains till the juice is ſo much drained off as to leave it in a proper condition for being formed into balls; which is done by labourers, with apparatus for the purpoſe, and then laid upon trays to be conveyed to the drying ranges, in which they are placed upon grating-ſhelves that ſlide on ſledges in the drying-houſes. Theſe are placed on the ſides of galleries, for the convenience of being eaſily depoſited upon them and removed again. It is kept in theſe till it is ſufficiently dried to be laid up in other rooms, until the whole of the crop has undergone the ſame operations, and the workmen are ready to manufacture it.

It is ſtated in the Corrected Lincolnſhire Report on Agriculture, that to prepare it for uſe in the art of dyeing, it is neceſſary for it to take on a proper ſtate of fermentation, which is accompliſhed in the courſe of ſeven or eight weeks, and, in the technical language of the art, is termed *couching*. It is effected by regrinding the balls, in the ſame mill as before, to a fine powder, and then ſpreading it upon the floors of the rooms in which the balls were formed, to the thickneſs of about three feet; where it is then moiſtened with water, ſo as to keep it in a proper ſlow ſtate of fermentation; and ſo managed by turning that it may pervade the whole in an equal manner. In this buſineſs, the direction of an experienced workman is neceſſary. In the turning, it is of much importance that the parts of the materials be perfectly divided, which can only be effected by a nice management of the ſhovel: and it is added that much advantage has been found in the goodneſs of the woad, from the drying and ſtoring of it being performed in a careful manner. When this attention is neglected, the woad will not, on being broken between the finger and thumb, draw out into fine hair-like filaments, or, in the technical language of the manufacturer, *beaver* well; as the uſe of this ſubſtance in the blue vat of the dyer, is not merely to afford the colour of the plant, but, by bringing on a very gentle fermentation, excite the indigo in the ſame vat to yield its colouring principle more perfectly. This is even neceſſary for its own colouring-matter being fully imparted. The ſubſtance ſhould, therefore, be ſo prepared in the different operations as to produce this effect in the moſt certain and perfect manner. When the heat in the proceſs of couching has gone too far, the ſubſtance will be what is termed *foxy*; and when it has not proceeded to a ſufficient degree, it will be what is called *heavy*. If the material be good, it does not ſoil the fingers on being rubbed between them; but ſuch as is heavy does. In the concluſion of the proceſs, the cooling is effected in ſo gradual a manner, as to render it not fit for taking on the ſame proceſs; and of courſe proper for being preſerved in caſks, or in any other way. It is then ready for uſe.

The preparation of woad for dyeing, as practiſed in France, is minutely deſcribed by Aſtruc, in his Memoirs for a Natural Hiſtory of Languedoc. The plant puts forth at firſt five or ſix upright leaves, about a foot long, and ſix inches broad: when theſe hang downwards, and turn yellow, they are fit for gathering: five crops are gathered in one year. The leaves are carried directly to a mill, much reſembling the oil or tan-mills, and ground into a ſmooth paſte. If this proceſs was deferred for ſome time,

they would putrefy, and fend forth an infupportable ftench. The pafte is laid in heaps, preffed clofe and fmooth, and the blackifh cruft, which forms on the outfide, re-united if it happens to crack: if this was neglected, little worms would be produced in the cracks, and the woad would lofe a part of its ftrength. After lying for fifteen days, the heaps are opened, the cruft rubbed and mixed with the infide, and the matter formed into oval balls, which are preffed clofe and folid in wooden moulds. Thefe are dried upon hurdles: in the fun, they turn black on the outfide; in a clofe place, yellowifh, efpecially if the weather be rainy: the dealers in this commodity prefer the firft, though it is faid the workmen find no inconfiderable difference betwixt the two. The good balls are diftinguifhed by their being weighty, of an agreeable fmell, and when rubbed of a violet colour within. For the ufe of the dyer, thefe balls require a farther preparation: they are beat with wooden mallets, on a brick or ftone floor, into a grofs powder; which is heaped up in the middle of the room to the height of four feet, a fpace being left for paffing round the fides. The powder, moiftened with water, ferments, grows hot, and throws out a thick fetid fume. It is fhovelled backwards and forwards, and moiftened every day for twelve days; after which it is ftirred lefs frequently, without watering, and at length made into a heap for the dyer.

The powder thus prepared gives only brownifh tinctures, of different fhades, to water, to rectified fpirit of wine, to volatile alkaline fpirits, and to fixed alkaline lixivia: rubbed on paper, it communicates a green ftain. On diluting the powder with boiling water, and after ftanding fome hours in a clofe veffel, adding about one-twentieth part of its weight of lime newly flacked, digefting in a gentle warmth, and ftirring the whole together every three or four hours, a new fermentation begins, a blue froth arifes to the furface, and the liquor, though it appears itfelf of a reddifh colour, dyes woollen of a green, which, like the green from indigo, changes in the air to a blue. This is one of the niceft proceffes in the art of dyeing, and does not well fucceed in the way of a fmall experiment.

Aftruc propofes the manufacturing of frefh woad leaves in Europe, after the fame manner as the indigo plant is manufactured in America; and thus preparing from it a blue fecula fimilar to indigo, which from his own experiments he has found to be practicable. Such a management would doubtlefs be accompanied with fome advantages, though poffibly woad fo prepared might lofe thofe qualities which now render it, in a large bufinefs, preferable on fome accounts to indigo, as occafioning greater difpatch when once the vat is ready, and giving out its colour lefs haftily, fo as to be better fitted for dyeing very light fhades. Neumann's Chem. by Lewis, p. 437, &c.

The ancient Gauls and Britons ufed to dye or ftain their bodies with this plant, and were probably led from this application of it to ufe it for dyeing cloth.

Some hold that it was from this plant glafs took its denomination; though others derive both *glafs* and *glaftum* from the Britifh *glafs*, which to this day denotes a blue colour. See Glass.

A woad blue is a very deep blue, almoft black; and is the bafe of fo many forts of colours, that the dyers have a fcale, by which they compofe the divers cafts or degrees of woad, from the brighteft to the deepeft.

Woad, in *Botany*. (See Isatis.) There are four fpecies.

The broad-leaved woad is cultivated in feveral parts of England for the purpofes of dyeing, being ufed as a foundation for many of the dark colours.

Some feed down the leaves of woad in winter with fheep; a practice which Mr. Miller condemns.

Woad grows wild in fome parts of France, and on the coafts of the Baltic fea: the wild woad, and that which is cultivated for the ufe of dyers, appear to be of the fame fpecies.

Befide the plant properly fignified by the name woad, which dyes a blue colour, we have two others known in our Englifh herbals under that name, as alfo that of *wold* or *weld*. Thefe are both called by the common people *dyer's weed*, and are the *luteola* and the *genifta tinctoria*.

The ancients confounded all thefe three plants alfo under the fame names. Paulus Ægineta feems to make them all the fame plant; and Neophytus, fpeaking of the *ifatis*, or our woad, properly fo called, fays, that it was called by the Latins *lutum*. This *lutum* has been by fome underftood to mean the *luteola*, and by others the *genifta tinctoria*; but the latter opinion only is right, for it is defcribed to us by the ancients as having leaves like the *linum*, or flax, and flowers like the broom.

Woad-*Mill* and *Houfe*, that fort of mill and houfe which is neceffary and proper for preparing and fitting this kind of fubftance for the ufe of the dyer. The reprefentation of a mill and excellent apparatus for effecting the preparation of the woad plant, which is made ufe of by Mr. Cartwright, with much fuccefs and advantage, in Lincolnfhire, may be feen in the fecond volume of the "General Dictionary of Agriculture and Hufbandry."

Wool

WOOL, in *Natural Hiſtory* and *Manufactures*, Latin *lana*, *lanicium*, Fr. *laine*, ſignifies ſoft hair or down, more particularly that of ſheep, but is applied to the ſoft hair of other animals, as of the vicunna, commonly called Vigonia wool, that of the yak of Tartary, &c.; and alſo to fine vegetable fibres, as cotton. The Romans applied the term extenſively to the ſoft hair or down of all quadrupeds, and even to that of birds, as lana anſerina, the wool or down of the gooſe; lana caprina, goat's-wool.

They alſo applied the term to vegetable ſubſtances:

——" Nemora Æthiopium molli canentia lana."
Virg. Georg. ii. 120.

" The trees of Ethiopia, white with ſoft wool, or cotton." The diſtinction between wool and hair is rather arbitrary than natural, conſiſting in the greater or leſſer degrees of fineneſs, ſoftneſs, and pliability of the fibres. When they poſſeſs theſe properties ſo far as to admit of their being ſpun and woven into a texture ſufficiently pliable to be uſed as an article of dreſs, they are called wool. The gradations between wool and hair on the ſkins of ſome animals are often too minute to admit of accurate diſtinction. The fleeces of many ſheep contain fibres ſo hard and coarſe, that they may moſt properly be called hair; and ſome hairy animals produce on part of their ſkins fibres poſſeſſing all the properties of wool; even in fleeces from the ſheep, we may ſometimes obſerve the very ſame fibre to be a coarſe hair at one end, and at the other end a comparatively ſoft wool. The power of words, when inaccurately applied in retarding the progreſs of improvement, may frequently be traced in the moſt common occurrences of life, and we are perſuaded it has had no inconſiderable effect in this inſtance, in preventing the cultivation of wool, in Europe, on the ſkins of other animals beſides ſheep. No one will deny that it is impoſſible to produce wool on the backs of the ox or the aſs, if we reſtrict the term wool to the fleece of the ſheep; but if by wool we mean a ſoft fine hair, poſſeſſing all the properties which render it ſuitable to be ſpun, woven, and fulled, to make cloth, the oxen of Thibet and the aſſes of Chili do produce and have for centuries produced ſuch wool. Many of the aſſes and oxen even in this kingdom have ſoft woolly tufts of hair on ſome parts of their ſkins, and if ſuch cattle were ſelected, and the breed cultivated, it is probable we might obtain from them a valuable addition to the materials on which national induſtry might be profitably employed.

Sheep's-wool appears to be the product of cultivation; we know of no wild animal which reſembles the wool-bearing ſheep. The argali, from which all the varieties of ſheep are ſuppoſed to be derived, is covered with ſhort hair, at the bottom of which, cloſe to the ſkin, there is a ſofter hair, or down. (See ARGALI and SHEEP.) This is not peculiar to the argali; almoſt all quadrupeds inhabiting cold climates are covered in the ſame manner with a ſoft hair or down, which is protected by a coat of longer and coarſer hair. By removal to a temperate climate, or when placed under the foſtering care of man, and protected from the inclemencies of the weather, and ſupplied regularly with food, the coarſe long hair falls off, and the animal retains only the ſofter and ſhorter hair, or wool. It is alſo obſerved that European ſheep, removed to tropical climates and much expoſed, ſoon become languid and ſickly, and loſe their fleece, which is ſucceeded by a covering of ſhort coarſe hair. Sheep in expoſed ſituations in Europe often produce ſhort coarſe white hairs called kemps, intermixed with the finer wool; on removal to a warmer ſituation, and to a richer paſture, the coarſe hairs fall off, and do not grow again. Theſe facts are ſufficient to prove the effect of cultivation on the fleece; and it muſt be obſerved that ſheep's-wool of a good quality is never found but in thoſe countries which have been the ſeats of the arts, and where a conſiderable degree of luxury or refinement exiſts, or has once prevailed. This is a ſtrong preſumptive proof that ſuch wool has been originally obtained by a careful and long-continued attention to the ſelection of thoſe ſheep which produced the fineſt and moſt valued fleeces.

Angora, the ancient Ancyra, the former ſeat of arts and manufactures, ſtill retains its breed of fine-woolled animals, among which the goat at the preſent time produces a fleece nearly equal to ſilk in luſtre and fineneſs; and the cat and the rabbit of that diſtrict yet produce fine long wool. Damaſcus, and the other ancient cities of Aſia Minor, preſerve

in their vicinity the traces of the former cultivation of fine-woolled animals. The Tarentine fine-woolled ſheep, ſo much valued by the Greeks and Romans, were obtained from Aſia Minor, and were on that account ſometimes called Aſianæ. It is highly probable that theſe ſheep came originally from the more eaſtern ſeats of luxury, where the ſoft fleeces are now grown, of which the ſhawls and cloths of India are fabricated.

In countries where manufactures have once flouriſhed, their effects continue for a long time viſible in the race of ſheep which ſtill remain there. Even in the preſent condition of the fleeces from Barbary and the adjoining ſtates, the experienced eye may perceive the veſtiges of a fine-woolled race of ſheep, degenerated by utter neglect, in a climate naturally unfavourable to the production of fine wool. In Sicily and the ſouthern parts of Italy, the remains of the ancient Tarentine breed preſerve to the preſent day a race of fine-woolled ſheep, but greatly degenerated by neglect. In Portugal the fine-woolled ſheep retain more of their original purity, but are ſtill much neglected. In Spain attention to the growth of fine wool appears never to have been entirely loſt ſight of, and it is here that the race of fine-woolled ſheep exiſt in the higheſt degree of perfection, though, as we ſhall afterwards ſtate, probably inferior in ſome important qualities to the original Tarentine race. Some writers have aſſerted that fine wool is the reſult of climate and food; but this is not the fact, though we admit that both have ſome influence on the quality of wool. It is the breed alone that primarily determines the fineneſs of the fleece; this has been ably demonſtrated by the experiments of lord Sommerville, Dr. Parry of Bath, and others in this country, and by experiments on a larger ſcale in Sweden, Denmark, Saxony, and France.

It has been aſcertained by Mr. Bakewell of Diſhley, in Leiceſterſhire, that the form of animals might be changed by ſelecting ſuch as had any remarkable peculiarities, and continuing to breed from them for a few generations, when a new race is eſtabliſhed, in which theſe peculiarities continue permanent. It has been aſcertained by careful obſervations, both of cattle-breeders and phyſiologiſts, that in producing a new breed from two varieties of the ſame ſpecies, the female has more influence over the form of the progeny than the male; but with reſpect to wool the caſe is reverſed, the quality of the fleece depending more on the ſire than the dam. Beginning to breed from a coarſe-woolled ewe and a pure fine-woolled ram, the produce of the firſt croſs will have a fleece approaching one-half to the fineneſs of that of the ram; and continuing to croſs this progeny with a fine-woolled ram, equal to the firſt in quality, the fleece of the ſcore and croſs will approach three-fourths to the fineneſs of the firſt, and in a few croſſes more will be brought to an equal quality. If we ſtate it numerically, and ſuppoſe the wool of the ewe to be twice as coarſe as that of the ram, or as 320 to 160, the firſt croſs will have the fibre reduced to 240, the ſecond to 200, the third to 180, the fourth to 170, the fifth to 165, the ſixth to 162½, which to all practical purpoſes may be regarded as equal to the firſt number. This ratio of approximation may be ſtated as correct on a large ſcale of experiment. If we breed with a fine-woolled ewe and a coarſe-woolled ram, the ſeries would be reverſed, and in a few generations all veſtiges of the fine-woolled race would be nearly, if not entirely, extinct. The ancient Romans, in the time of Columella, ſeem to have been fully aware of the effects of breed on the fineneſs of the wool, and as much as 200*l.* ſterling was paid for a fine-woolled ram.

When a flock of fine-woolled ſheep are once formed, they can only be kept pure by ſelecting and preſerving the fineſt-woolled rams, and moſt carefully avoiding all intermixture with ſheep from coarſer-woolled flocks that may exiſt in the country. Where this is neglected, the quality of the wool will ſoon be debaſed.

But ſuppoſing all the flocks in a country were of the fine-woolled race, accidental varieties of coarſe-woolled ſheep will occur among them, or of ſheep having fleeces intermixed with coarſe hair. If theſe be not carefully examined and removed, the wool will deteriorate, and more ſo where the climate is variable, and the ſheep are expoſed to great and ſudden viciſſitudes of temperature.

What has been ſtated may ſuffice to explain the circumſtance of fine-woolled breeds of ſheep being only found in the vicinity of preſent or ancient manufactures, or where they have been tranſported from ſuch diſtricts. Wherever fine-woolled ſheep are neglected by man, the wool becomes either coarſe, or intermixed with coarſe hairs; the latter is the caſe in the Shetland iſles, and in all countries where the arts and manufactures have been entirely deſtroyed, and ignorant barbarians have ſucceeded as the poſſeſſors of the ſoil.

Moſt ancient writers on wool, and even many moderns, ſeem not to be aware of any difference in wools, except the fineneſs or coarſeneſs of the fibre; but the length of the fibre conſtitutes a far more important diſtinctive character. Long wool, or what is called combing-wool, differs more from ſhort or clothing wool, in the uſes to which it is applied, and the mode of manufacture, than flax from cotton.

Sheep's-wool may, therefore, be divided into two kinds. Short wool, or clothing-wool, and long or combing wool: each of theſe kinds may be ſubdivided into a variety of ſorts, according to their degrees of fineneſs. This proceſs is the proper labour of the wool-ſorter.

Short wool, or clothing-wool, may vary in length from one to three or four inches; if it be longer it requires to be cut or broken, to prepare it for the further proceſſes of the cloth manufacture. Short or clothing wool is always carded or broken upon an inſtrument with fine ſhort teeth, by which the fibres are opened and ſpread in every direction, and the fabrics made from it are ſubjected to the proceſs of felting, which we ſhall afterwards deſcribe. By this proceſs, the fibres become matted together, and the texture rendered more compact.

Long or combing wool may vary in length from three to eight or ten inches: it is prepared on a comb or inſtrument, with rows of long ſteel teeth, which open the fibres, and arrange them longitudinally: in the thread ſpun from combed wool, the fibres or filaments of the wool are arranged in the ſame manner, or ſimilar to thoſe of flax, and the pieces when woven are not ſubjected to the proceſs of felting.

The ſhorter combing-wools are principally uſed for hoſe, and are ſpun ſofter than the longer combing-wools, the former being made into what is called hard worſted yarn, and the latter into ſoft worſted yarn.

Short Clothing-Wool.—The principal qualities deſerving attention in clothing-wools are the regular fineneſs of the hair or pile, its ſoftneſs and tendency to felt, the length and ſoundneſs of the ſtaple, and the colour. The wool-buyer alſo regards as important the clean ſtate of the fleece, and to the grower its weight is particularly deſerving attention; for in fleeces equally fine, from ſheep of the ſame ſize, ſome may be much heavier than others, the fibres of wool being grown cloſer to each other on the ſkin.

The fineneſs of the hair or fibre can only be eſtimated to any uſeful purpoſe, in the woollen manufacture, by the wool-ſorter or wool dealer, accuſtomed by long habit to

discern a minute difference, which is quite imperceptible to common obſervers, and ſcarcely appreciable by the moſt powerful microſcopes. Of the various attempts that have been made to reduce the fineneſs of wool to a certain ſtandard, by admeaſurement with a micrometer, we ſhall afterwards ſpeak. From ſome experiments we have made, as well as from thoſe made by Mr. Luccock, Dr. Parry, and others, we may eſtimate the thickneſs of the hair of the fineſt Spaniſh and Saxony wool to be not more than the fifteen-hundredth part of an inch, and that of the fineſt native Engliſh to be from twelve to thirteen-hundredth parts, whilſt the inferior ſorts gradually increaſe to the ſix-hundreth part of an inch and more. A difference in the ſize of theſe fibres, too minute to be noticed by the common obſerver, may occaſion a difference of 40 *per cent.* or more in the value of the wool. The fineneſs of the hair has been ever conſidered as an important quality ſince the clothing manufacture emerged from its rudeſt ſtate. Fine wool was formerly valued becauſe a finer thread could be ſpun from it, and a thinner fabric made, than from the coarſer wools; but ſince recent mechanical improvements have been introduced into the woollen manufacture, it has been found practicable to ſpin coarſe wools to the ſame length as the finer wools were formerly ſpun to. It is well known, however, to cloth-manufacturers, that whatever be the fineneſs of the yarn, unleſs the wool be fine, it is impoſſible to make a fine, compact, and even cloth, in which the thread ſhall be covered with a thick ſoft pile; nor would a thin cloth made from coarſe wool have the ſame durability or appearance as one from fine wool of equal weight *per* yard. Fine wool will, therefore, always preſerve a ſuperior value to the coarſe; indeed it was long conſidered as the principal and almoſt the only quality deſerving the attention of the wool-grower, the wool-ſtapler, and the clothier.

The regular fineneſs of the fibre is alſo an object of conſiderable importance; the lower end of the ſtaple, or that part of the fleece neareſt the ſkin, will ſometimes be very fine, and the upper part coarſe. In ſome fine fleeces there will frequently be an intermixture of long, ſilvery, coarſe hairs, and in other fine fleeces an intermixture of ſhort, thick, opaque hairs, called kemps. When the wool is thus irregularly fine or intermixed, it is technically called not being *true grown*. The fine fleeces of Spain and Portugal, particularly of the latter country, are many of them injured by the intermixture of the long ſilvery hairs before-mentioned: whether this be owing to the original Tarentine breed having been croſſed with the coarſe-woolled native ſheep of Spain, (ſee the article Sheep,) and ſtill preſerving a tendency to revert to their firſt condition, or whether it be the effect of heat on the ſkin, is uncertain. The Saxony fleeces, from the ſame breed, removed to colder climates, are generally free from this defect. The coarſe ſhort hairs, or kemps, are not uncommon in ſome of the fine-woolled flocks of England and Wales, particularly thoſe which are more expoſed to the inclemencies of the weather, and have a ſcanty or irregular ſupply of food. It has been obſerved, in the firſt part of the article Sheep, that in ſome flocks the proportion of fine wool in each fleece is much greater than in others, for in few or none is the wool grown uniformly fine over the whole body.

On the Merino ſheep the fleece is more regular, whatever be the degree of fineneſs, than on any of our native Engliſh fine-woolled breeds. The Merino fleece admits of a diviſion into four ſorts, the *refina*, the *fina*, and the *tercera*, with a very minute portion of coarſe from the ſhanks and head, which is not ſent to market. The three ſorts are diſtinguiſhed in commerce by the marks R, F, and T. On the average, there will be in each fleece nearly three-fourths of the beſt or R wool. The ſecond and third ſorts, or the F and T, will alſo contain a conſiderable portion as fine as the beſt; but being ſhorter and diſcoloured, or intermixed with coarſe hairs, which require their locks to be ſeparated from the beſt ſort, or the refina.

In the native Engliſh fleeces, however fine ſome part may be, the proportion of the beſt ſort rarely exceeds one-third part, and is frequently not more than one-ſixth part of the whole fleece.

The value of the beſt part of a Spaniſh fleece, or the R wool, varies greatly in different flocks. When this ſort, from the moſt eſteemed flocks, may be worth ſix ſhillings and ſixpence *per* pound in the Engliſh market, the R wool from another flock may not be worth more than three ſhillings and ſixpence. The F and T wools are from 25 to 50 *per cent.* lower than the firſt ſort: thus, the inferior ſorts from the fineſt piles may be of greater value than the beſt ſort or R wool of other piles; but they are never intermixed by the dealers, as they are applicable to different fabrics. In the Engliſh mode of wool-ſorting, there will frequently be eight or ten ſorts in a ſingle fleece; and if the beſt wool of one fleece be not equal to the fineſt ſort, it is thrown to a ſecond, third, or fourth, or a ſtill lower ſort, which is of an equal degree of fineneſs with it. The beſt Engliſh ſhort native fleeces, ſuch as the fine Norfolk and South Down, are generally divided by the wool-ſorter into the following ſorts, varying in degree of fineneſs from each other, which are called,

Prime,
Choice,
Super,
Head,
Downrights,
Seconds,
Fine abb,
Coarſe abb,
Livery,
Short coarſe or breech wool.

Beſides theſe ſorts of white clothing wool, two and generally three ſorts of grey wool are made, conſiſting of locks which may be black, or intermixed with grey hairs. Some wool-ſorters alſo throw out any remarkably fine locks in the prime, and make a ſmall quantity of a ſuperior ſort, which they call picklock. The origin of ſome of the above names is obſcure, but the names of the finer ſorts appear to indicate either a progreſſive improvement in the quality of the wool, or in the art of wool-ſorting. The relative value of each ſort varies conſiderably, according to the greater demand for coarſe, fine, or middle cloths; and the variation during and ſince the late war in the Spaniſh peninſula has been much increaſed by temporary cauſes. Before that period, when the R wool of good Spaniſh piles ſold at from five ſhillings and ſixpence to ſix ſhillings *per* pound, the prime from Herefordſhire fleeces was ſold at about three ſhillings and ſixpence, and that from the Norfolk and South Down from three ſhillings to three ſhillings and twopence *per* pound. The higher price of the Herefordſhire was in part owing to its being in a cleaner ſtate. The Spaniſh wool is alſo cleaner than any of the Engliſh wools, being ſcoured after it is ſhorn; but the latter is only imperfectly waſhed on the ſheep, previouſly to its being ſhorn. A pack of Engliſh clothing wool of 240 pounds weight, in its marketable ſtate, will waſte about 70 pounds in the proceſs of the manufacture: the ſame quantity of Spaniſh wool, as ſent to market, will not waſte more than 48 pounds

on the average. This contributes to enhance the difference between the prices of each, as well as the superior finenefs of the latter.

Different wool-forters make a confiderable variation in their modes of forting the fame kind of fleeces: fome divide them into more forts than others; but the following table will fhew what may be taken as the average relative value of each fort, when the prime is worth about three fhillings and two-pence *per* pound, and may ferve to fhew the fkill required to eftimate the value of fine Englifh wool in the fleece.

		s.	d.		s.	d.
Prime	- -	3	0	to	3	4
Choice	- -	2	4	to	2	8
Super	- -	2	0	to	2	2
Head	- -	1	8	to	1	10
Downrights	-	1	5	to	1	6
Seconds	- -	1	3	to	1	4
Fine abb	-	1	0	to	1	1
Coarfe ditto	-	0	9	to	0	10
Livery	- -	0	8	to	0	10
Short coarfe	-	0	7	to	0	8

The demand for coarfe woollen goods having greatly increafed of late, the prices of the lower forts are confiderably advanced from the above-ftated prices, and are at prefent as under:

		s.	d.	
Short coarfe	-	1	4	
Livery	- -	1	5	
Fine abb	-	1	6	
Seconds	- -	1	7	
Downrights	-	1	8	*per* pound in London.
Head	- -	1	10	
Super	- -	2	0	
Choice	- -	2	2	
Prime	- -	2	6	
Picklock	-	3	0	

The Softnefs of fine clothing Wool is next in importance to the finenefs of the fibre, though it has been too little attended to in the culture of Englifh wool. This quality is not dependent on the finenefs of the fibre; it confifts in the peculiar feel which approaches to that of filk or down, but in which the wool of all European fheep is inferior to that of Eaftern Afia, or to the wool of the vicunna, or lama of Peru and Chili. In foreign European wools there are different degrees of this property, where the fibre is equally fine. In our native Englifh wools, the like difference exifts between the foftnefs of wool poffeffing the fame degree of finenefs, but grown in different diftricts. In the harder wool, the fibre is elaftic and hard to the touch, and cloth made from it has the fame harfh feel; it is alfo more loofe in its texture, and the furface of the thread is generally more bare. The difference in the value of cloth from two kinds of wool, equally fine, but one diftinguifhed for its foftnefs, and the other for the contrary quality, is fuch, that with the fame procefs and expence of manufacture, the one will make a cloth more valuable than the other from twenty to twenty-five *per cent.*

Though the Englifh woollen manufactures had been carried on for fo long a period, the caufe of this difference in cloths made from wool equally fine was but very imperfectly known till the prefent century. Mr. Robert Bakewell, then of Wakefield in Yorkfhire, firft directed the attention of wool-growers and manufacturers to this fubject, in a work, entitled "Obfervations on the Influence of Soil and Climate on Wool." The reafon why the manufacturers remained fo long ignorant refpecting it arofe, he obferved, from the manner in which the woollen-trade had been carried on in Yorkfhire, the great feat of the manufacture of Englifh clothing-wool, the divifion of employment there not permitting the wool-dealer, or even the clothier, to witnefs the final refult of the procefs. The wool-buyer in the diftant counties, and the wool-forter, who divided the fleece, were equally unacquainted with the cloth manufacture. The Yorkfhire clothier fold his goods in an undreffed, and often in an undyed ftate; they were bought and finifhed by the cloth merchant, who was formerly unacquainted with the previous proceffes of the manufacture, or the qualities of wool. In a promifcuous lot of undreffed cloth bought at the fame price, and apparently of the fame quality in the rough ftate, if fome pieces were finifhed much better and fofter than others, it was attributed to lucky chance, the patron divinity of the ignorant. Mr. Bakewell proved that the hardnefs of Englifh wools does not depend on the nature of the food, or even entirely on the breed; it is the effect of the foil acting on the furface of the fleece. The wools from chalk diftricts, or light dry calcareous foils, have the natural yolk or moifture abforbed by the particles of calcareous earth that penetrate the fleece, and the wool is thereby rendered hard. The fame effect is produced on a fkin where lime is ufed; it may alfo be produced by keeping wool for a longer or fhorter time in a dry hot temperature; and when wool has been fo dried, no procefs will reftore to it its priftine foftnefs. On the contrary, wools grown on rich loamy argillaceous foils are always diftinguifhed for their foftnefs. The quantity of greafe or yolk in the fleece has a confiderable degree of influence on the foftnefs of Merino wool, the pile being fo clofe as in a confiderable degree to prevent the earthy particles from penetrating the fleece; but in all Englifh fleeces the wool is grown thinner on the fkin, and admits the more eafy accefs of the abforbent particles. Expofure to the direct rays of a fummer fun has alfo a tendency to injure the foft quality of the wool. We fhall have occafion to refer to the methods recommended by Mr. Bakewell to improve the foftnefs of wool on foils naturally unfavourable to its growth.

Of fine European wools, the Saxony generally poffeffes a greater degree of foftnefs than the Spanifh, which we believe to be owing to the fheep being lefs expofed to the action of light and heat. The native fine Italian wool, before the introduction of the Merino race, poffeffed a confiderable degree of foftnefs, judging from wools which we have feen from thence, but they were deficient in foundnefs, and not *true grown.* The wools on the chalk foils in the fouthern and eaftern fide of England are generally hard, except, as in Kent, where the chalk is covered by thick argillaceous beds. Nottingham foreft, Chamwood foreft in Leicefterfhire, and fome parts of Shropfhire, produced not the fineft, but fome of the fofteft wools in England before the late inclofures. The Cheviot hills in Cumberland are not paftured by the fineft-woolled Englifh fheep, but their fleeces poffefs a degree of foftnefs exceeding any from the other diftricts of England, and they are rendered foft by artificial means, which we fhall defcribe. It is ftill fomewhat uncertain, whether there are two diftinct breeds of fheep, from which the fine fhawl wool of India are grown; or whether one fpecies of the animal which yields it is not to be claffed with the goat. The fleeces from India, which we have feen, are grown on a very fmall fheep; clofe to the fkin, there is a wool as foft as the fofteft fur; this is covered by long coarfe hairs growing through it. When the wool is once fhorn, the feparation of thefe hairs from the foft

wool is a work of extreme difficulty; but on the back of the sheep we believe the separation can be made with great ease. The softness of the Indian wool is not even distantly approached in the very softest Merino fleeces from Saxony and Spain; this may be proved by comparing the finest cassimere cloth from Saxony wool, with the shawls or shawl-cloth of India. The ancient Tarentine sheep, called by way of excellence 'molles oves,' were treated with peculiar care by the Romans, and clothed in skins, which we believe was intended to preserve the softness of the wool, as it is still practised in some parts of Asia for that purpose. In Europe no experiments have been made directly to improve the softness of wool, though wool approaching in softness to that of India would be a most valuable acquisition to our manufactures. To be convinced of this, it need only be stated, that the yarn from Indian wool has been sold here at three guineas *per* pound, not on account of the superior fineness of the spinning, but for the softness of the wool. For coarse goods, indeed, such as blankets, carpets, and cloths called duffields, raised with a hairy pile, a considerable degree of hardness or elasticity of the fibre is an advantage; but in all the finer articles of the woollen or worsted manufacture, the opposite quality is of great value.

The felting property of wool is intimately connected with its softness, the softest wools having the greatest tendency to felt, and the hard wools are all defective in this respect. The felting property appears to depend on a peculiar structure of the surface of the fibres, by which they are disposed to move in one direction more easily than another. This is perceptible in drawing a hair through the fingers, first from the end to the point, and again from the point to the end; in one direction the hair feels perfectly smooth, in the other direction a peculiar roughness is felt. The cause of this is supposed to be owing to the surface of the fibres having laminæ, like the scales of fishes, with the edges laid over each other. Indeed in the furs of some animals we have observed with a powerful microscope, that the surface is composed of laminæ laid over each other, resembling the arrangement of the leaves of the artichoke. On this property the process of hat-making depends; the short fibres of the fur being repeatedly compressed, move and interlock with each other, so as to form a compact substance; this motion is further aided by heat and moisture. A similar process takes place to a certain degree in cloth subjected to the strokes of a fulling-mill; the fibres cohere, and the piece contracts in length and breadth, and its texture is rendered more compact and uniform. This process is essential to the beauty and strength of woollen cloth; and it is observed, that the softer wools felt in much less time than the harder, and form a closer pile on the surface of the cloth, on which account it is a common practice to mix a certain quantity of soft wool with the hard, to enable the former to felt with more facility.

The length and soundness of the staple of clothing wool is the quality next to be considered. By the staple of wool is meant the separate locks into which the fleece naturally divides in the skin, each lock consisting of a certain number of fibres, which collectively are called the staple.

The best length of staple for fine clothing-wool, if found, is from two to three inches. If it be longer it requires breaking down to prepare it for the process of carding. Saxony wool, being generally more tender than the Spanish, and more easily broken down, is sometimes four or five inches long; but as it works down easily, it is preferred, on account of the length of its staple, for such goods which require fine spinning, as cassimeres, pelisse cloth, and shawls. Much of the English clothing-wool of a middle quality is grown longer than is desirable for the purpose of the clothier, and when found is thrown out for the hosiery trade, if the demand for the latter be great. As the grower could not shorten the length of the staple without diminishing the weight of the fleece, he has no motive to induce him to grow shorter wool; but the object might be obtained with much benefit to himself by shearing twice in the year, once the latter end of April, and again the latter end of August; the wool would then be grown of a suitable length for the card, and from experiments that have been made we believe the weight would exceed what can be obtained from one clip: the increase would not be less than fifteen *per cent.*, and the condition of the sheep thereby improved.

The soundness of the staple in clothing-wools is not so important as in combing-wools; but for some kinds of colours which injure the wool, it is particularly desirable that the fibre should be sound and strong; this is judged of by drawing out the staple and pulling it by both ends. The soundness and strength of the staple depend primarily on the healthy state of the animal, and on a sufficient supply of food. The staple on some parts of the fleece will always be more tender than on other parts, but by mixture they tend to form a dense pile on the surface of the cloth.

The colour of the fleece should always approach as much as possible to the purest white, because such wool is not only necessary for cloths dressed white, but for all cloths to be dyed bright colours, for which a clear white ground is required, to give a due degree of richness and lustre. It is probable that all sheep's-wool was first of a black or reddish colour: the latter is often referred to by the ancients. Before the invention of dyeing, coloured wool must have had a preference to white; but after the act of communicating beautiful colours to the fleece, white wool would be in the greatest demand, and those sheep which had white fleeces would be selected to breed from. The most ancient flocks of sheep which we have any record of are those of Laban and Jacob, described in the book of Genesis. The fleeces appear to have been principally brown, or spotted and striped, which was in all probability the general colour of the flocks throughout that part of Asia. We learn that in the course of twenty years a great change was effected in the colour of a large portion of the sheep of Laban: though Jacob appears to have concealed from his father-in-law the method by which this change was effected, we are expressly told in the sequel that it was by crossing with rams which had fleeces of the colours required.

Dark-brown or black woolled sheep are not uncommon in many parts of the European flocks, but such wool being of less value than the white, these sheep ought always to be expelled. Some of the English fine-woolled sheep, as the Norfolk and South-Down, have black or grey faces and legs. In all such sheep there is a tendency to grow grey wool on some part of the body, or to produce some grey fibres intermixed with the fleece, which renders the wool unfit for many kinds of white goods; for though the black hairs may be too few or minute to be detected by the wool-sorter, yet when the cloth is stoved they will become visible, forming reddish spots, by which its appearance is much injured. The Herefordshire sheep, which have white faces, are entirely free from this defect, and yield a fleece without any admixture of grey hairs. We have no doubt that by carefully rejecting those sheep from the South-Down flocks, in which the grey is most apparent, this defect might be gradually removed. It is particularly desirable with respect

to theſe ſheep, as the wool grown on chalk ſoils, though leſs ſoft than on other ſoils, is generally whiter, and better ſuited to ſuch goods which require the proceſs of bleaching or ſtoving, and do not require to be ſo much fulled as many other cloths.

The ancients were ſo well aware of the neceſſity of expelling dark-coloured wool from their flocks, that in ſelecting the ſheep to breed from, they did not truſt to the colour of the fleece alone, but carefully examined the mouth and tongue of the ram, and if the leaſt blackneſs or ſwarthineſs appeared he was immediately rejected; and though ſome moderns have doubted the uſe of this precaution, we believe it was well founded.

> " Illum autem, quamvis aries ſit candidus ipſe,
> Nigra ſubeſt udo tantum cui lingua palato,
> Rejice, ne maculis infuſcet vellera pullis
> Naſcentem." Vir. Georg. iii.

Pliny alſo ſtates, that particular attention was on this account had to the colour of the mouth. " Arietum maxime ſpectantur ora." We are informed that this kind of inſpection takes place in the Spaniſh flocks at preſent, a practice in all probability derived from the Roman ſhepherds, as we believe the flock to have been from thoſe of Italy, or the Tarentine breed. The colour of the ſoil on which ſheep graze, if very dark or red, communicates to the wool a tint more or leſs ſtrong, which is indelible, and renders ſuch wool leſs proper for cloths or hoſiery goods that are to be finiſhed white; for though the colour may be improved by ſtoving, yet on waſhing the cloths, they ſoon return to a browniſh or yellowiſh tint. The tint from the ſoil is, however, rarely of ſufficient ſtrength to be regarded for dyed goods, excepting for exceedingly light colours.

The cleanneſs of wool is principally regarded by the purchaſer, as it affects the weight. To the grower thoſe fleeces are generally the moſt profitable that are well filled with the greaſe, or yolk as it is called, becauſe it keeps the wool in a ſound ſtate, and improves its ſoftneſs. It ought, however, to be waſhed out as much as poſſible before it is expoſed to ſale. The fleeces of the Merino ſheep are more plentifully ſupplied with yolk than thoſe of any of our native fine-woolled breeds; indeed it is ſo abundant, that the Engliſh mode of waſhing on the back of the ſheep will ſcarcely produce any effect upon the fleece. The yolk or greaſe in the fleece appears, from the experiments made upon it by M. Vauquelin, to be a native ſoap, conſiſting principally of animal oil combined with potaſh. It is moſt copiouſly produced in thoſe breeds which grow the fineſt and ſofteſt wool, and is always moſt abundant on thoſe parts of the animal which yield the fineſt parts of the fleece. To this ſubject we ſhall again refer in treating of the improvement of wool. This yolk, though ſo beneficial to the wool in a growing ſtate, becomes injurious to it when ſhorn; for if the fleeces remain piled in an unwaſhed ſtate, a fermentation takes place, the yolk becomes hard, and the fibre is rendered hard and brittle. This effect takes place more rapidly in hot weather. The Spaniards remove this yolk in a great meaſure by waſhing the wool after it is ſhorn and ſorted. In Saxony fine-woolled ſheep of the ſame race are waſhed in tubs with warm water, ſoap-lees, and urine, and afterwards in clean water.

In England the wool is waſhed on the back of the ſheep by immerging the animal in water, and ſqueezing the fleece with the hand. From theſe different modes of waſhing, the wool is left more or leſs pure. Mr. Bakewell, in his Obſervations on the Influence of Soil and Climate on Wool, has given the following table, containing a ſtatement of the quantity of neat wool in every hundred pounds, taken on an average of each ſort, and ſuppoſing each to be free from lumps of pitch employed in marking the wool, and cleared from what are called the *dog-locks*. The firſt column repreſents the average weight after the wool has been ſcoured perfectly clean with ſoap and water, and dried; the ſecond the amount of waſte.

	Pure Wool.	Waſte.
100 lbs. of Engliſh wool waſhed on the ſheep's back - - - - -	75	25
Ditto Saxony fleece-wool - -	80	20
Ditto Spaniſh R, or refine - -	88	12
Ditto Spaniſh and Portugal unwaſhed -	75	55
Ditto Engliſh fleeces unwaſhed - -	60	40
Ditto lightly greaſed wools of Northumberland waſhed on the ſheep's back	65	35

Hence it is obvious, that the ſtate of the fleece with reſpect to cleanneſs is an object of great importance to the wool-buyer. The Engliſh Merino ſheep, from the difficulty of waſhing the wool on the ſheep's back, have generally been ſhorn in an unwaſhed ſtate, and the wool offered for ſale in this ſtate. The purchaſers were frequently unacquainted with the great amount of the loſs it would ſuffer by waſhing, and were much diſappointed at the reſult. This circumſtance, we conceive, more than any other, tended to prejudice the manufacturer againſt the Anglo-Merino wool. The wool is alſo injured by remaining in the greaſe, as we have before ſtated, and though this has been contradicted, we have no heſitation in aſſerting the fact from our own experience. Indeed the French manufacturers of fine cloth aſſert, that the beſt wools from Spain, though cleared in a great meaſure from the yolk, yet ſtill retain ſufficient to injure the wool if it be ſuffered to grow old when it is packed, the yolk becoming rancid and hard, and communicating the latter property to the wool. We have frequently obſerved this effect in the wools from Portugal, that retain a greater portion of the yolk than thoſe from Spain.

After wool has been waſhed in the uſual manner practiſed in England, and piled or packed, a certain proceſs takes place in eight or nine weeks, called *ſweating*. This is well known to wool-dealers and manufacturers, but has not been before noticed by any writer that we are acquainted with. It is evidently an incipient fermentation of the remaining yolk; and the inner part of the pack or pile becomes ſenſibly warm. This proceſs produces a certain change in the wool, whereby it becomes in a better condition for manufacturing, being what is called in the north of England leſs *fuzzy*. This effect reſults from a diminution of the natural elaſticity of the fibre.

When this fermentation takes place in unwaſhed wool, it proceeds farther, and injures the colour and ſoundneſs of the ſtaple or fibre. A ſimilar effect is produced in wool or cloth which has been oiled, and remains ſome time in an unſcoured ſtate. Inſtances of ſpontaneous combuſtion from heaps of refuſe wool remaining in a greaſy ſtate have been known to occur, and occaſion the moſt ſerious accidents in woollen factories.

The weight of the fleece is an object of great importance to the grower. It is generally ſuppoſed by the Engliſh wool-dealers, that an increaſe of weight implied an increaſe of coarſeneſs; indeed the words coarſe and heavy are conſidered by them as ſynonymous, but this is not abſolutely

the cafe ; a fleece grown upon the fame animal may be increafed in weight either by the fibres becoming coarfer, or by their being grown longer, or by a greater number of fibres being grown in the fame fkin. To the wool-grower it can never anfwer to increafe the weight of the fleece on fmall fine-woolled fheep, by growing the wool coarfer ; if this be his object, the long-woolled breeds of fheep are to be preferred. He may produce wool fomewhat longer by increafing the quantity of food ; but it generally lofes fomething of its finenefs, and is lefs fuitable for the cloth trade. He may, however, increafe the weight confiderably by felecting fuch breeds as grow the wool clofe upon the fkin, and are thickly covered with wool over every part of the body. In this refpect, the Merino fheep have greatly the advantage over any of the native breeds of Englifh fheep ; many of them yielding from three to four pounds of pure wool, whilft the fineft Englifh fleeces rarely exceed two pounds, and would lofe one-fourth of this weight when brought to a pure ftate by fcouring. It has been doubted whether all fheep's-wool, when clean, poffeffes the fame fpecific gravity ; but admitting there may be fome variation in the wool from different piles, we conceive that it is too minute to deferve the attention of the wool-grower or manufacturer.

The filaments of fine wool being fo minute, it requires an eye habituated by long experience to appreciate the relative finenefs of two piles, which may differ in value as much as twenty-five *per cent.* Even thofe who have been long practifed in fuch examinations find it difficult to form immediately a correct opinion of the finenefs, if they are removed for a few weeks from all opportunity of viewing wool. It is not furprifing then that the wool-grower, who only directs his attention to the fubject during one part of the year, fhould often be unable to judge whether his wool has improved or not fince the preceding fummer. On this account it would be highly defirable that fome eafy and correct method of admeafurement by the micrometer could be invented, which might enable the obferver to decide this with certainty. Mr. Daubenton employed a graduated fcale, adapting it to the eye-piece of a compound microfcope ; but his method does not admit of accuracy. Mr. Luccock made ufe of a more fimple inftrument, which we have feen ; it confifted of a lens about half an inch in focal length, adjufted to a graduated fcale. On this fcale a number of fibres were ftretched and compreffed by a flider and fcrew into a given fpace ; the filaments covering this fpace were then counted by the aid of the lens, and a number of admeafurements being taken of the fame fort, the mean of the whole was fuppofed to give the correct diameter of the filament. In this method, however, fome of the filaments muft unavoidably overlap part of the others, on which account a greater number will be feen in a given fpace than there would be were the whole diameter of each fibre vifible. The error refulting from this may be ftated at one-fifth. Thus Mr. Luccock makes the beft Englifh wool to meafure the fourteen-hundredth part of an inch, which is finer than the beft Spanifh, as meafured by Dr. Parry, by a more accurate but more laborious method. According to Mr. Luccock, a fample of moderately fine Spanifh wool reached to the fixteen-hundredth part of an inch ; according to Dr. Parry, the very beft Spanifh is not fmaller than the fourteen-hundredth part of an inch.

With the above deduction of one-fifth, which we believe to be a near approximation to correctnefs, the diameter of the fibres of the beft Englifh wool, as forted in the ufual method, will be nearly as follows :

	Parts of an Inch
Prime - - -	$\frac{1}{1120}$
Choice - - -	$\frac{1}{1024}$
Super - - -	$\frac{1}{928}$
Head - - -	$\frac{1}{800}$
Downrights - -	$\frac{1}{740}$
Seconds - - -	$\frac{1}{640}$
Abb - - - -	$\frac{1}{580}$
Fine livery (variable) -	$\frac{1}{480}$

The method of meafurement adopted by Mr. Luccock might be fufficiently correct with the deduction of one-fifth, were the inftrument always ufed by the fame perfon, and a fimilar degree of preffure given in each experiment ; but as this is required, it becomes uncertain in its refults, and inadequate to practical purpofes.

Dr. Parry's method of meafurement is effected with an inftrument fimilar in principle to the lamp micrometer of Dr. Herfchel, of which an account is publifhed in the Philofophical Tranfactions for 1782. (See MICROMETER.) An object of a known diameter being placed in the focus of a compound microfcope, and ftrongly illuminated, a piece of white paper is placed horizontally at fome diftance beneath it ; then looking through the microfcope with one eye, and keeping the other fteadily open, you will fee the object apparently projected on the paper, which is to be meafured, whilft viewing it, with a pair of compaffes. Divide the length of the image fo meafured with the known diameter of the object, which will give the magnifying power of the microfcope. This being found, place the object you wifh to meafure in the focus, and projecting its image on the paper as before, meafure it with the compaffes, and divide the refult by the magnifying power, which will be the real magnitude of the object required.

The light of a lamp is to be preferred to day-light, and the fibres to be meafured are to be *ftretched* on a glafs, and waxed down at both ends. The under fide of the glafs fhould be blackened with Indian ink, except in three parts, the middle, and near the two ends. The unblackened fpaces being placed in the focus of the microfcope, ten or more filaments may be examined and meafured fucceffively, both in the middle part of the glafs, and near the ends, which will give the diameter of the filament at the upper and lower end of the ftaple, and in the middle. Each lock of ten filaments being thus examined in three different parts, the mean of the three meafurements muft be taken for the mean diameter of each filament, and the mean diameter of the ten filaments may be taken for the finenefs of the whole lock.

In place of the blackened glafs, we would recommend a thin flide of ivory or brafs, about five inches in length, and half an inch in breadth, with three tranfverfe flits or openings, one in the middle, and the two others about three-fourths of an inch from each end. On this flide the filaments may be ftretched, it will not be liable to break, and the edges of the filaments will be more correctly defined than when a plate of glafs is placed under them.

The farther the paper is removed from the eye, the larger will be the apparent fpace covered by the image of the object, but it muft not be too far for the hand to meafure it with compaffes. But if in place of the compaffes we have a fheet of pafteboard graduated into minute divifions from a black line upwards, and a fliding index be adjufted, the pafteboard may be placed at a much greater diftance, the obferver adjufting the flide, until the edge of it and the black line coincide with both edges of the filament. An

horizontal poſition for the microſcope will be the moſt convenient, illuminating the object with a lamp and lens. In this way, the apparent diameter may be greatly increaſed, and we think the obſervations might be made with greater eaſe and accuracy.

By the above method the diameter of very minute filaments may be aſcertained, and minute differences detected, which the unaſſiſted eye is unable to detect. We are aware, however, that it requires ſome addreſs and time to enable the obſerver to manage the inſtrument, on which account it cannot, we fear, be made generally uſeful.

The following admeaſurements of different fine wools were taken with Dr. Parry's inſtrument; the firſt column repreſents the outward end of the filament, the ſecond the middle, and the third the bottom, in fractional parts of an inch; the latter column the mean of ten filaments of the ſame wool.

TABLE of comparative Diameters of the Filaments of various Clothing Wools, by Dr. Parry.

	Outward End.	Middle.	Inner End.	Mean.
Spaniſh Ewe	1/[illegible]	1/[illegible]	1/[illegible]	1/[illegible]
Laſteria Pile	1/[illegible]	1/[illegible]	1/[illegible]	1/[illegible]
Ewe	1/[illegible]	1/[illegible]	1/[illegible]	1/[illegible]
Coronet Pile	1/[illegible]	1/[illegible]	1/[illegible]	1/[illegible]
Native Merino Ram	1/[illegible]	1/[illegible]	1/[illegible]	1/[illegible]
Saxon	1/[illegible]	1/[illegible]	1/[illegible]	1/[illegible]
Pictet's Merino Ram	1/[illegible]	1/[illegible]	1/[illegible]	1/[illegible]
Beſt Negrette Pile	1/[illegible]	1/[illegible]	1/[illegible]	1/[illegible]
Alva Pile	1/[illegible]	1/[illegible]	1/[illegible]	1/[illegible]
Rambouillet Ewe	1/[illegible]	1/[illegible]	1/[illegible]	1/[illegible]
Imperial Pile	1/[illegible]	1/[illegible]	1/[illegible]	1/[illegible]
Morre	1/[illegible]	1/[illegible]	1/[illegible]	1/[illegible]
Ryeland	1/[illegible]	1/[illegible]	1/[illegible]	1/[illegible]
South Down	1/[illegible]	1/[illegible]	1/[illegible]	1/[illegible]
Anglo Negrette Ram	1/[illegible]	1/[illegible]	1/[illegible]	1/[illegible]
Negrette Ram, Marquis of Bath	1/[illegible]	1/[illegible]	1/[illegible]	1/[illegible]
Charenton Ram	1/[illegible]	1/[illegible]	1/[illegible]	1/[illegible]
Ryeland Ram	1/[illegible]	1/[illegible]	1/[illegible]	1/[illegible]
Cape, 4th Croſs	1/[illegible]	1/[illegible]	1/[illegible]	1/[illegible]
Wilts Ewe	1/[illegible]	1/[illegible]	1/[illegible]	1/[illegible]

Long Wool, or *Combing Wool*, being prepared for ſpinning by a proceſs entirely different from that of ſhort or clothing wool, and the pieces made from it being finiſhed in a very different manner, the qualities moſt required in this kind of wool are length and ſoundneſs of the ſtaple, without which the fleece is unſuited for the comb. The fineneſs of the hair is a ſecondary quality, required only in certain kinds of goods. The wool-comb is an inſtrument of ſimple conſtruction, conſiſting of a wooden handle, with a tranſverſe piece or head, in which are inſerted three rows of long ſteel teeth. The wool, which is to be combed after being clean ſcoured, dried, and oiled, is firſt drawn upon theſe teeth with the hand, until the comb is ſufficiently loaded. It is then placed on the knee of the comber, and another comb of a ſimilar kind is drawn through it, and the operation is repeated till all the hairs or fibres are combed ſmooth in one direction. This operation requires conſiderable ſtrength, but the comb being previouſly heated, and the wool thoroughly oiled, facilitates the proceſs. When completed the combed wool is drawn off with the fingers, forming what is called a *ſliver;* the ſhorter part of the wool ſticks in the teeth of the comb, and is called the *noyl:* this is ſold to the clothiers.

From the above deſcription, it is evident that if the ſtaple of the wool be not ſound, the greater part of it will be broken by the proceſs of combing, and form noyls. The ſtaple muſt alſo have a ſufficient degree of length for the combs to operate upon it. Length and ſoundneſs of the ſtaple are therefore the moſt eſſential and characteriſtic qualities of combing-wools.

Long wools may be claſſed into two kinds: firſt, thoſe ſuited for the manufacture of hard yarn for worſted pieces; and ſecond, thoſe ſuited for the manufacture of ſoft yarn uſed for hoſiery. The former require a greater length of ſtaple than the latter. The firſt may therefore be called long combing-wool, and the latter ſhort combing-wool; between theſe there are gradations of wool, which may be applied to either purpoſe.

Long combing-wool ſhould have the ſtaple from ſix inches to eight, ten, or even twelve, in length. Before the recent improvements in ſpinning by machinery, a very great length of ſtaple was conſidered as an excellence in long combing-wools; and on this account the hog-wool, or the firſt fleeces from ſheep which had not been ſhorn when lambs, was more valuable than the wether wool from the ſame flock, and bore a higher price than the former, by at leaſt fifteen *per cent.* Since that time the wether wool has riſen in relative value on account of the evenneſs of the ſtaple, each lock being nearly equally thick at both ends; but the ſtaple of hog-wool is pointed, or what is technically called *ſpirey.* Eight inches, if the wool be ſound, may be regarded as a very proper length for heavy combing-wools. The longer ſtapled wool was formerly worked by itſelf, and uſed for the finer ſpun yarn, or mixed in ſmall quantities with the wether wool, to improve the ſpinning. It is found that an equal length of ſtaple contributes to the evenneſs of the thread when ſpun by machinery, and a very great length of ſtaple is rather injurious than otherwiſe in the proceſs of machine ſpinning. To the wool-grower, however, it muſt always be deſirable to increaſe the length of his heavy combing fleeces, as he thereby materially increaſes the weight; and we have not yet learned that the price has ever been reduced on this account, for if the wool be too long for ſome branches of the worſted manufacture, there are others in which it may be worked with advantage.

The length of the ſtaple may be increaſed by a plentiful ſupply of nutritious food. The ſame effect may alſo be produced by letting the wool remain a longer time on the ſheep before it is ſhorn. We have ſeen a ſtaple of Lincolnſhire wool which was twenty inches in length: it had grown two years without ſhearing. This, however, would be unattended with any advantage to the grower. The more frequently ſheep are ſhorn, provided the wool is ſufficiently long, the greater will be the weight grown in a given time on the ſame animal; for, from obſervations which we have made, we are ſatiſfied that wool is grown more rapidly immediately after the ſheep are ſhorn than at any other time. Length of ſtaple in wool depends primarily on the breed, but may be more affected by culture than many other qualities of the fleece. The ſoundneſs of the ſtaple may be eaſily judged of by pulling both ends of it with the fingers with conſiderable force. In weak or unſound wool the ſtaple eaſily breaks in one or more parts, and on obſerving it, it will be ſeen that the fibres are much thinner in the part which breaks. This is occaſioned either by a deficient ſup-

ply of food, by diſeaſe, or by inclement ſeaſons, which cauſe a ſtoppage in the growth of the fleece. This goes on to a greater or leſs degree. In ſome inſtances, the ſtoppage has been ſo entire that the upper part of the ſtaple is nearly ſeparated from the lower, and is only connected with it by a few filaments: in ſuch caſes, the ſtoppage has continued for a conſiderable time, and the bottom part of the ſtaple may be conſidered as a new fleece, protruding the old one from the ſkin. Connected with the ſoundneſs of wool, there is another property required; this is, that the ſtaple be free and open, or that the fibres ſhall not be matted or felted together; an effect which takes place frequently when the wool is unſound. It is in fact a natural felting of the wool on the back of the animal, when by any cauſe it has ceaſed to grow. Sometimes the lower part of the fleece next the ſkin will be ſo completely matted as to form a ſubſtance nearly as hard as a hat, and will hold to the ſkin by a few hairs only. Theſe are called cotted fleeces; all approach to this ſtate is peculiarly injurious to combing-wools. The wool-buyers generally throw out the cotted and unſound fleeces when they pack the wool from the grower, and buy them at a very reduced price. The ſoftneſs of combing-wool, though of leſs importance than in clothing-wool, yet enhances its value, as it is found that ſuch wool makes a cloſer and ſofter thread, and in every proceſs of the manufacture finiſhes more *kindly*. Combing-wools grown on light calcareous ſoils are deficient in this reſpect; ſuch are the combing-wools of Oxfordſhire and the Cotſwold hills, which are formed of that ſpecies of lime-ſtone called oolite, or roe-ſtone. A copious ſupply of the yolk is neceſſary to the healthy condition of the fleece, and as this in many flocks is nearly equal in weight to the wool, the fleeces contain from ſix to eight pounds or more of it before they are waſhed, for in the unwaſhed ſtate they often weigh eighteen pounds in many of the long-woolled flocks in England.

The whiteneſs of the fleece is leſs important in the long combing than in clothing wool, provided it be free from grey hairs. The latter circumſtance does not frequently occur in combing-wools. There is, however, a peculiar colour communicated by the ſoil, which is ſometimes ſo deep as to injure the wool for particular uſes, and what is of more importance, there is a dingy-brown colour given to the fleece by impoveriſhed keeping or diſeaſe, which is called a *winter ſtain*; it is a ſure indication that the wool is not in a thoroughly ſound ſtate, and ſuch fleeces are carefully thrown out by the wool-ſorter, being only ſuited for thoſe goods which are to be dyed dark colours.

The fineneſs of heavy combing-wool is of leſs importance than the other qualities. In every fleece of this kind there will be a certain ſmall portion of ſhort clothing-wool on the ſhanks, the belly, the throat, and the buttocks. The clothing-wool from ſuch fleeces is not often divided into more than two or three low ſorts, and the combing-wool is ſeldom thrown into more than four ſorts, that is, two ſorts of the hog-wool, and two ſorts of the wether-wool, of which three-fourths, if the fleece be good, will form the beſt ſort in each.

There is, however, a fine long combing-wool which is required for bombazines and the finer kinds of worſted goods; this is moſt frequently ſelected from the longer parts of clothing fleeces, and admits a diviſion into four or five ſorts, the fineſt being equal in hair to that of the head or ſuper in clothing-wool; whereas the beſt ſort of the common heavy combing-wools ſeldom ranges higher in point of fineneſs than the coarſeſt ſort of clothing-wool above the breech locks; *viz.* the low abb and the livery.

Short combing or hoſiery wool requires a different length of ſtaple, according to its fineneſs: for the better ſorts, the ſtaple ſhould not be ſhorter than four or five inches; the lower ſorts may range as high as eight inches. A greater length than this is not deſirable for any kind of ſoft worſted. What has been ſaid of the ſoundneſs and fineneſs of ſtaple required for long combing-wool, applies equally to the hoſiery wool, but in this the fineneſs of the hair and ſoftneſs are of more importance. Moſt of the fleeces which yield fine combing-wool produce nearly an equal quantity of ſhort wool, which is thrown in the ſame manner as the regular clothing ſorts. The combing ſorts for the hoſiery are generally called,

Super matching,
Fine matching,
Fine drawing,
Altered drawing,
Brown drawing,
Saycaſt.

The names of theſe ſorts derive their origin from ancient proceſſes of the manufacture, with which we are unacquainted at preſent. The lower ſort, or ſaycaſt, was probably at firſt the long coarſe combing-wool, thrown out for the manufacture of ſays, of which we have frequent mention in the earlieſt hiſtory of the woollen trade in England. The relative value of theſe ſorts, compared with each other, varies according to the demand for the finer or coarſer kinds of hoſiery, and is alſo affected by the clothing trade. When any clothing ſort which ranges in fineneſs with one of the combing ſorts is in great demand, the wool-ſorter will break down the ſhorter combing-wool of this ſort, and throw it to the clothing-wool, which enhances the price of the former by making it ſcarce. The fineneſs of theſe ſorts out of the beſt combing-wools, ſtated numerically, as compared with clothing ſorts, will be nearly as under, in the fractional parts of an inch.

Super matching	- -	$\frac{1}{860}$
Fine matching	- -	$\frac{1}{780}$
Fine drawing	- -	$\frac{1}{700}$
Altered drawing	- -	$\frac{1}{600}$
Brown drawing	- -	$\frac{1}{500}$
Saycaſt	-	$\frac{1}{450}$

Moſt of the beſt ſorters throw out the hog combing-wool from the beſt ſorts, making a ſuperfine hog for the bombazine trade, hog-wool being leſs ſuitable for the hoſiery, which does not require yarn ſo finely ſpun as for hard yarn.

As all the different ſorts of ſhort combing-wool, together with ſeveral ſorts of clothing-wool, will frequently occur in one Engliſh fleece, it is obviouſly the intereſt of the grower that his fleece ſhould produce as great a proportion of the beſt ſorts as can be done without materially diminiſhing the weight.

Skin Wool, or *Pelt Wool*, is the wool ſeparated from the ſkins of ſlaughtered ſheep by the fellmonger. The quantity of this wool, in a country like England, where ſo much animal food is conſumed, is very conſiderable, and has been eſtimated at near 50,000 packs of 240lbs. *per annum*, for England and Wales. Soon after ſhearing, the ſkin-wool is too ſhort to be worked by itſelf, and is generally kept and mixed in with the longer wools. The proceſs by which wool is ſeparated from the ſkins has a tendency to make it hard, and deſtroy or injure its felting or milling property, on which account ſhort-ſkin wools are ſeldom uſed for the manufacture of cloth, but more generally for flannels, ſerges, and thoſe kinds of goods which require little or no milling;

the finest kinds are much used for stockings made of yarn from carded wool. In the spring, when the wool on the skins has acquired a considerable length, it is thrown into combing sorts; the finer kinds are used for knitting hosiery yarn, and the coarser for hard yarn for the warps of serges and other goods, having a warp of combed and a weft of carded wool. The value of skin-wool is seldom equal to that of fleece-wool of the same degree of length and fineness, owing to the felting property being injured, which renders it more unfit for the manufacture of woollen cloth.

Lamb's Wool.—The wool of the lamb is, with certain exceptions, softer than that of sheep's-wool, from the same flocks. It possesses the property of felting in a remarkable degree, and on this account is principally manufactured into hats, except skin lamb's-wool, which losing its felting property in a great degree, is employed in the manufacture of flannels and woollen yarn for lamb's-wool hosiery. In the northern parts of Europe, the lambs of some of the breeds of sheep possess a fleece so delicately soft, that it constitutes a most valuable fur, being dressed on the skin, and used as a costly article of attire. According to Pallas, the inhabitants of the Ukrain and Podoli, as soon as the lamb is dropped, (which comes into the world with a pretty wavy skin, even without the assistance of art,) to augment its beauty, and make it bring a higher price, sew it up in a sort of coarse linen shirt, so as to keep up a constant gentle pressure on the wool, pouring warm water over it every day to make it soft and sleek; only letting out the bandage a little from time to time as the animal increases in size, but still keeping it tight enough to effect their purpose, which is to lay the *wool* in beautiful glossy ringlets, and thereby produce a delicate species of fur in great request for lining clothes and morning-gowns. By this treatment, the staple of the fine soft wool which rises in the infancy of the lamb takes a handsome arrangement; and the animal is killed younger or older according to the species of fur intended to be produced; from a short glossy nap, like satin, only fit from its thinness for the purpose mentioned above, to a warm thick fur for a winter great-coat. The first of these furs in estimation and price is a fine black, that looks like silk damask; an inferior black fur comes next, much thicker, used for *pelisses*, or *shubes*, as the upper winter garb worn out of doors is called; and the least in estimation is the whitest, except it be of a very pure colour and silky appearance, where it is a rival to the first; especially for night-gowns, a very common dress both morning and evening amongst the Russians; particularly in the interior parts of the empire.

The Boucharian sheep, as described by Pallas, grows a compact, soft, and elastic wool, which is elegantly formed into frizzled ringlets. In the lamb, the wool is formed into delicate little circular waves, as if pressed close to the skin by art; but when taken from the mother, or killed immediately after birth, they are still more beautiful, and often elegantly marbled with feathered waves, like silk damask. These three furs are the finest and most precious of the kind known to Europe and the East; they are brought to us by the Boucharian Tartars and Persians, who sell them dear. The most prized are, the *blue*, the black, and the silver grey; but of the *unborn lamb-skins*, as the fine glossy thin furs are called, which so much resemble silk damask, the fine black is dearest and most esteemed. To obtain these valuable furs, the Boucharian Tartars purchase whole flocks of male lambs just dropped from their mothers: as to kill a female till past the age of breeding is held as a kind of crime by all Tartar hordes; such is their reverence for an animal which constitutes their greatest riches, and the propagation and care of which are the great business of their lives; so that all the fur we see of this species sold by the Tartars are from young rams. The Boucharians are of opinion, that art is necessary to preserve these furs in their greatest beauty; and under that idea, keep the lambs under shades, &c. during the meridian ardour of the sun; but Dr. Pallas has reason to think, that these precautions are useless, as he observed that the same variety of sheep produced the same fine hues equal in every respect, without any sort of care, in the hands of the Kirguite Tartars.

It is very remarkable that the lamb's-wool, in many of the Merino flocks, is coarser than the sheep's-wool. In some of the flocks, the lambs are at first covered with coarse hair, which falls off afterwards, and they produce the finest wool.

Wool from other animals besides the sheep is employed in manufactures, and spun and woven into fabrics of different kinds, either unmixed or mixed with sheep's-wool. The goats of Thibet, which grow the fine shawl wool, produce it as a fine down at the bottom of the long coarse hair, with which the animals are covered. Many of the common goats in Europe grow a similar down, which, by cultivation, might become a valuable article of commerce. It is not, however, yet clearly ascertained, whether the shawls and shawl cloth of India are all manufactured from goat's-wool; part of it appears to be made from sheep's-wool peculiarly soft and fine. The Angora goat grows a hair extremely fine and silky, which is much used in some of the French worsted goods mixed with silk. This goat is properly a long-woolled animal. Dr. Anderson says, that the Angora goat will prosper and preserve its peculiarities in France and Sweden. The wool of the vicunna, called Vigonia wool, is generally of a reddish-fawn colour; it is peculiarly soft and silky, but intermixed with long coarse hairs, which are very difficult to separate. (See VICUNNA.) From the lama and pacos of Peru a stronger and longer stapled wool is obtained, which is sometimes white. Under a liberal government which protected and encouraged commerce, we have no doubt the fleeces of these animals might be greatly improved, and would become an article of great value. The wool from the yak of Tartary, and the musk ox of Hudson's bay, has yet received little attention. We have seen stockings made of the latter, and which are worn in that country; the wool was soft but not fine, and much intermixed with long coarse hairs.

The quantity of sheep's-wool annually grown in England and Wales was estimated, by persons in the wool trade examined before the house of commons in the year 1800, at six hundred thousand packs. Mr. Luccock, in his Treatise on Wool, seems to consider this estimate as greatly exceeding the real amount, and has given an estimate founded on the supposed extent of surface pastured by sheep, and the quantity of sheep *per* acre in each county. This table we subjoin, as the only attempt that we know of to determine the question on certain data; though we consider it only as an approximation to truth, and are inclined to believe that the quantity is under the real amount. Such is also the opinion of the most intelligent persons in the wool trade, whom we have had an opportunity of consulting.

From this table, it will appear that the total amount, including skin-wool and lamb's-wool, is somewhat short of four hundred thousand packs, which is probably one-fourth below the true quantity, could it be ascertained. Mr. Luccock is inclined to believe that the flocks of sheep in England and Wales are not so numerous as formerly, but he says those of Ireland and Scotland are rapidly increasing. Even in England and Wales, he says, we have

more than three millions of acres capable of being improved, and carrying a more numerous ſtock. We have two millions of ſheep whoſe fleeces are ſcarcely wool, and which might be brought to contribute their ſhare to ſupport the woollen manufacture, and to increaſe the wealth of the country.

It may be proper to remark, that the quantity of wool grown annually in England is more variable than is generally ſuppoſed, owing to the variable temperature of our climate. In long-continued and ſevere winters, the ſheep not obtaining the ſame quantity of food, and being alſo rendered leſs vigorous by the cold, do not grow ſo much wool as in milder ſeaſons. The difference between the weight of the fleeces grown in ſevere and in very mild ſeaſons, may be ſtated at one-fifth of the whole annual clip: indeed we believe it exceeds that proportion. About the year 1700, the annual value of Engliſh wool was eſtimated at two millions ſterling. If we ſuppoſe the average price at that time to have been eight-pence *per* pound, or eight pounds *per* pack, this will make the total weight of wool two hundred and fifty thouſand packs. Indeed when we conſider the improved ſtate of our agriculture, the great increaſe of our population, and of our woollen exports, we may fairly ſtate the preſent weight of wool grown to be double the amount of what it was at the period referred to. In a ſubſequent part of this article, it will be ſeen that the cloth manufactures of Yorkſhire, principally from Engliſh wools, have increaſed eight-fold in the laſt eighty years; and though the woollen manufactures have removed from ſome other ſituations, yet the great increaſe on the whole in England cannot be doubted. Since the date of Mr. Luccock's table in 1805, in conſequence of the high price of long combing-wool, the growers have paid more attention to the weight of their fleeces; and many who had rendered their fleeces lighter by exchanging the Lincolnſhire for the Leiceſter breeds of ſheep, have ſince been reverting to the former breed, or rather to a mixed breed, endeavouring to combine the improved form of the Leiceſter ſheep with the heavy fleece of the Lincoln. The quantity of long combing-wool grown annually is greater than it was even ten years ſince; the high and increaſing price and demand operating naturally as a premium for its cultivation.

Table I.—Shewing the Produce of Engliſh Long Wool.

Diſtrict.	County.	No. of Acres.	No. of Sheep.	Weight of Fleece.	No. of Packs.
Teeſwater -	Durham - - - - - -	100800	67200	9	2520
	Yorkſhire - - - - - -	61250	14310	8	477
Lincoln -	Holderneſs - - - - -	127680	84000	8	2800
	Lincoln rich land - - - -	413875	1241625	9	46561
	marſhes - - - - -	175000	87500	8	2916
	miſcellaneous land - -	758485	505657	8	16855
	Norfolk - - - - - -	55428	38500	7	1223
	Cambridge - - - - - -	187600	41688	8	1390
	Huntingdon - - - - -	87500	87500	7	2552
Leiceſter -	Leiceſter - - - - - -	398650	380528	7	11100
	Northampton - - - - -	560000	640000	6	16000
	Rutland - - - - - -	117000	114000	5	2370
	Warwick - - - - - -	182875	160000	5	3333
	Stafford - - - - - -	14000	3720	7	113
Kent - -	Romney Marſh - - - - -	46920	185000	7	5400
	Other Marſhes - - - - -	65000	108330	7	3160
Devonſhire -	South Hams - - - - -	387500	193750	8	6458
Cotſwold -	Glouceſter - - - - - -	200000	200000	8	6666
		3939563	4153308		131794

Slaughtered 1176770 Sheep

196128 Producing long-ſkin wool 5720 Packs.

Carrion wool 286

5434

Neat Total - 137228

TABLE II.—Englifh Short Wool.

Diftrict.	County.	No. of Acres.	No. of Sheep.	Weight of Fleece.	No. of Packs.
Norfolk	Norfolk	1260572	683704	2	5697
	Suffolk	817000	497000	2½	5176
	Cambridge	817600	67744	4	1128
	Huntingdon	144000	108000	4½	2000
	Bedford	268800	204000	5	4250
	Effex	778400	519000	3	6486
	Suffex Downs	211200	316800	2	2640
	Low Land	623840	547000	3	6837
	Kent	728000	524475	3¼	7000
	Hampfhire	774900	516600	3	6457
	Ifle of Wight	87500	61000	3¼	800
	Surrey	327600	283000	3	3540
Wiltfhire	Wiltfhire Downs	437000	583500	2¾	6684
	Pafture	235000	117500	3	1460
	Berkfhire	408800	306600	3¼	4151
	Oxford	380730	304584	Various.	5303
	Bucks	408800	222968	3	2787
	Herts	369600	277000	4½	5297
	Middlefex	76000	45000	4	750
Weftern	Dorfet	700000	632240	3¾	9880
	Devon	873700	436850	4	7280
	Cornwall	812000	203000	4	3382
	Somerfet	851200	500700	4½	9338
	Gloucefter	528000	355000	Various.	5400
Hereford	Hereford	672000	500000	2	4200
	Monmouth	322625	177619	Various.	1431
	Worcefter	369600	330504	3½	4820
	Shropfhire	739200	422034	2½	4397
	Stafford	549360	183120	2	1526
	Warwick	365925	182962	3	2287
	Leicefter	50000	20000	3½	291
	Lincoln	309120	123648	5½	2833
	Nottingham	435680	255147	Various.	4112
	Derby	553280	362400	3	4530
Heath	Chefter	588000	65000	Various.	926
	Lancafter	952000	310000	3½	4522
	York Weft Riding	1429250	383122	Various.	6678
	Eaft Riding	454720	306240	5	6380
	North Riding	1200000	365326	Various.	5939
	Weftmoreland	431200	378400	3½	3262
	Cumberland	856800	378400	3¾	5915
	Durham	414400	159385	5	3320
	Northumberland	1108800	538162	5½	12333
Welfh	North Wales	2035200	683040	2	5692
	South Wales	2284800	571200	1½	3570
	Ifle of Man				
		28412202	14854299		202737

			Packs Skin Wool.	
Slaughtered	4221748 sheep	3·25 / 2	28580	
Carrion	211087		1429	
Slaughter of long-wool sheep	980642	3	12258	
Carrion of ditto brought forward			286	
				42553
Total of fhort wool				245290
Ditto long ditto				137228
Wool from lambs flaughtered			2918	
Ditto fhorn			7800	
				10718
Grand total				393236

		lbs.	
N.B.—The average fleece of England, nearly -			
Do. ———————— short wool		4	
Do. ———————— long wool		10	
Do. stock *per* acre in England -			$\frac{3}{2}$ sh.
Do. do. long wool -			$\frac{20}{19}$ sh.
Do. do. short wool -			
Do. produce *per* acre long fleece wool - - -			
Do. do. short do.	1	5	
Do. do. long skin wool	0	5	
Do. do. short do. -	0	4	
Do. do. skin wool of the kingdom, nearly - -			

The wool of Scotland may, perhaps, be estimated at 70,000 packs, of which the greater part, particularly that grown in the Highlands, is of the very coarsest kind. Of the quantity of wool grown in Ireland, we can form no correct estimate, but it cannot be great. From the returns at the Custom-house, it appears that the quantity of wool imported from Ireland and the Isle of Man in 1816 amounted to about 2600 packs; whilst the value of woollens imported from England was upwards of 500,000*l.* sterling. The woollen and worsted manufactures in Ireland are no where on an extensive scale; perhaps 60,000 packs are the full amount of the wool annually shorn in Ireland: this was the amount stated about a century since.

The quantity of wool imported into England may be seen from the following return at the Custom-house for the year 1817, amounting to about thirty thousand packs. The qualities we have annexed in the last column.

An Account of the Quantity of Sheep and Lamb's Wool imported into Great Britain, in the Year ending 5th January 1817; distinguishing the Countries from whence imported.

Countries from whence imported.	Year ending 5th Jan. 1817.	Quality.
	lbs.	
Russia - - - -	228,673	Coarse.
Denmark - -	80,646	Principally coarse.
Iceland and Feroe -	33,395	Coarse.
Prussia - - -	16,712	Fine clothing-wool.
Germany - -	2,816,655	Principally ditto.
Holland - - -	143,390	Ditto.
Flanders - - -	77,625	Ditto.
France - - -	221,595	Ditto.
Portugal, &c. - -	493,277	Ditto.
Spain - - -	2,958,607	Ditto.
Gibraltar - - -	25,692	Coarse.
Italy - - -	108,234	Principally fine.
Turkey - - -	26,821	Fine.
Ireland and Isle of Man (produce)	600,377	Various, none very fine.
——— (foreign) -	1,171	
New Holland - -	13,611	Fine Merino.
Cape of Good Hope	9,623	Ditto.
United States of America - - -	43,465	Various.
Spanish colonies in South America -	206,454	Ditto.
Brasils - - -	5,512	Ditto.
British West Indies -	6,329	Ditto.
Total - -	8,117,864	

The whole of the imported wool, with scarcely an exception, is worked on the card, none of it being suited for the comb. The coarser kinds are principally employed for carpets, &c.; and the fine from Spain, Germany, Portugal, and France, supply our manufactures of superfine broad cloths, cassimeres, &c. So large a portion being of the finer kinds, the total value cannot be less than one million and a half pounds sterling.

Wool of New Holland.—The annual value and amount of the fine wool imported into England for our own manufactures being so great, we must surely applaud the meritorious exertions of those who attempt to supply the demand with the produce of our own country, or of our dependent colonies, and more particularly if they can raise this supply from parts where no wool was before grown. In this view, it cannot fail to be highly interesting to learn, that the exertions of one enlightened agriculturist have been eminently successful in spreading over an immense region dependent on England the very finest-woolled sheep, where the soil had never before yielded any produce serviceable to civilized man.

John Macarthur, esq. descended from an ancient family in Argyleshire, captain in a regiment then commanded by general Grose, went to New Holland in 1789. Fortunately for the future prosperity of the colony, his active spirit of inquiry and enterprise led him to direct his attention to the natural advantages which the soil and climate presented to the agriculturist, and having by purchase and grants obtained a considerable tract of country, he quitted the service in 1793, and commenced his farming operations. His stock at first consisted only of a few oxen and thirty Bengal ewes, growing a coarse kind of wool or hair. About the year 1795, he obtained from captain Kent, of the Royal Navy, one Merino ram and two ewes, purchased from the Dutch governor of the Cape of Good Hope. With these he began to cross his coarse-haired sheep, and to select the finest-woolled progeny to breed from. Having occasion to return to England in 1802, he brought over specimens of his wool, which were shewn to a body of the clothiers from the west of England, then in London on public business, who were so sensible of the advantages which might result from encouraging the growth of fine wool in the colony, that they presented a petition to the privy council, by whom Mr. Macarthur was examined. His plans being approved, the privy council recommended the secretary of state for the colonies to give him an additional grant of land, in a tract of country, from its fertility, called the cow-pastures, forming part of Camden county. On his return he took with him three Merino rams and two ewes, purchased from his majesty's flocks; and thus encouraged, he proceeded with rapid steps in the increase and improvement of his flocks, the climate being every way suited to secure the healthy condition of the sheep, and preserve the fineness of the wool.

The numbers increase four-fold every five years, so that his flocks already amounted to about four thousand sheep and lambs, including the fine and mixed breeds, when the unfortunate disputes with governor Blight, and the subsequent arrest of the latter, obliged Mr. Macarthur once more to return to England, and in some degree interrupted the progress of improvement. In 1817 his flocks had increased to about seven thousand, and the wool which has been sent to this country at different times, is become an important source of profit, the better sort being equal to the best Merino piles from Spain or Saxony. What we have seen more nearly resembles the latter, and were they both in the same state of cleanness, the most experienced eye could not discern any difference between them in fineness of the hair, length of staple, soundness, colour, or other properties.

The wool has been hitherto washed on the sheep's back in the English method, by which it is not rendered so clean as by the Spanish or German mode; but making allowance for the additional waste, its value is equal to that of the very best Merino wool imported from any part of Europe.

The quantity imported this year is about eighteen thousand pounds weight, and a farther arrival is expected. The laudable example of Mr. Macarthur has been followed by other persons in the colony, and the total amount of wool sent from thence this year is about fifty thousand pounds weight; and such is the spirit of agricultural improvement, that at the annual sales of sheep established by Mr. Macarthur, rams and ewes have been sold at from ten to thirty guineas each. Though the absence of Mr. Macarthur impeded the progress of improvement, yet this will be more than compensated by the valuable information he has obtained with respect to the management and improvement of his flocks, from observations made on the continent; and he has further benefited the colony by taking back with him a selection of olive-trees, vines, and oranges. The dryness and mildness of the climate of New Holland, and the almost total absence of briars and underwood, are extremely favourable to sheep. His stock is divided into flocks of about four hundred, with shepherds and Spanish dogs to each. Under these propitious circumstances, and as the flocks double in number every thirty months, we may anticipate, that in the course of twenty or twenty-five years, the importation of fine wool from this colony will be fully equal to the total amount at present imported into England from all the different countries of Europe. It might repay the exertions of this enlightened agriculturist, and of the British government, could they procure from India the animals, whether sheep or goats, which yield the peculiarly soft wool for shawls. This would be a most valuable article, and is much wanted by our manufacturers.

There can scarcely be a doubt, that under the favourable climate of the British settlements in New Holland, all the Asiatic wool-bearing animals, particularly those of Cashmere and Thibet, might be introduced with every prospect of success. The coarse wool grown in the colony is chiefly manufactured in the country for domestic use. It is estimated that there are at present sixty thousand sheep in the colony, and a little perseverance and attention would suffice to change the coarse-woolled breeds into finer ones; a change which is at present rapidly taking place, and deserves the greatest encouragement, as wool is the only article of produce which the colonists have at present to export in exchange for British manufactured goods.

The Improvement of Wool depends primarily on attention to the breed of sheep, but there are various circumstances of soil, climate, and food, which are important to be regarded. The experiments that have been made in various parts of Europe within the last half century, have sufficiently removed the prejudice that long prevailed, respecting the impossibility of growing the finest clothing-wool in almost every part of the globe where sheep will subsist and thrive. It is different with the long combing-wools, to grow which in perfection, luxuriant pastures seem absolutely requisite, and these cannot be obtained under a parching sun, nor could the animal subsist in tropical climates, covered with such a load of wool as is grown on our sheep in Lincolnshire. Under such circumstances, an entire change seems to take place in the animal system; the long-woolled sheep become diseased and feverish, and only recover by casting the fleece, which is replaced by a coat of short hair. The rich pasture in England, and the opposite coasts of Flanders, seem more favourable to the growth of heavy combing fleeces, than any other country in the known world; and the Leicestershire and Lincolnshire sheep seem every way well suited to these pastures, and the prices of the wool obtained at present are sufficient to secure attention to its cultivation. At one period, indeed, during the American revolution, the price of long combing-wool not being more than about three-pence *per* pound, the growers turned their attention principally to the improvement of the carcase, and neglected the weight of the fleece. At present the price is about eighteen-pence, and the average weight being about eight pounds, the wool forms an important object, and the growers are endeavouring to increase the weight of their fleeces. For the common purposes of the worsted manufactures, this wool is so well suited as to leave nothing further to be desired; and it is this kind which foreign manufacturers are so desirous to obtain from us. In many situations, however, where heavy long-woolled sheep are introduced, and where the soil is not sufficiently rich to grow it in perfection, it would be possible to grow a fleece weighing five or six pounds of very fine combing-wool, by crossing the long-woolled ewes with the Anglo-Merino rams. The increasing demand for finer goods, and the great improvement made in the spinning of combing-wool by machinery, make such a change desirable where the pastures are not sufficiently rich to bear the heavy long-woolled breeds of Leicester and Lincoln.

In many cold and exposed situations it would be desirable to provide better shelter for the flocks; and the practice of *greasing*, hereafter described, might be introduced with great advantage, and would tend to preserve the sheep and improve the quality of the wool.

The experiments made on the fine-woolled sheep on a large scale in different parts of Europe, prove that the peculiarities of food and climate have comparatively small influence on the quality of clothing-wool, and that it may be grown equally fine in situations where the sheep are confined and kept on dry meat a great part of the year, as in Saxony, Sweden, and Denmark. It may also be grown in the richest pastures, provided the pastures be over-stocked, to keep the herbage bare. There cannot, however, be a doubt, that a dry light soil, particularly in the moist climate of England, is most favourable to the health of the sheep, and to the quality of the wool.

The experiments that have been made in England on the Merino sheep have not been so successful as in other countries, principally arising from two causes.

In the first place, the demand for meat in England will always make the wool but a secondary object with the grazier, and no cross of the Merino sheep with the English has yet produced a race that equal in symmetry of form the South Down sheep, or that will produce the same quantity of meat to the butcher in the same space of time, and with the same food. In the second place, the mode of washing the Merino and Anglo-Merino wool in England will, so long as it is practised, prevent the wool from obtaining its proper value in the market. From the great quantity of natural yolk or grease in the Merino fleece, it is impossible to wash the wool on the sheep's back by mere immersion in water. In Spain no attempts are made to wash the wool upon the sheep's back, but all the fleeces of a pile are regularly sorted, and the different sorts scoured and dried before the wool is packed. But where the quantity of wool which any one grower possesses is small, as in England, it would not answer to send for wool-sorters from a distance; and to wash the wool before it is sorted, would so intermingle the fine with the coarse locks, as to render the regular sorting extremely difficult and expensive. In

Saxony and Sweden the wool is washed on the sheep's backs. The following account of the process is thus described by baron Schulz. The sheep are first washed with one part clear ley, and two parts lukewarm water, and then in another tub with less ley in the water; after which the sheep are washed, laying them always on their backs, with their heads up, in a tub with clean water; and lastly, there is poured on the sheep, when standing on the ground, a sufficient quantity of water, which is as much as possible squeezed out of the wool. The sheep are afterwards driven into an unpastured meadow adjoining, and remain there, to prevent their soiling themselves in the sheep-house. They remain there a day and a night, or longer, till the wool be dry, which in fine weather will be in three days. Some persons wash their sheep twice, but the wool becomes harder in consequence of it, and has a greyer appearance.

The great quantity of grease which the finest Spanish wool contains at the first washing mixes with the ley-water, and makes it quite soapy; but this grease is wanting in the second washing, so that the water is not in the least softened. Some mode of washing like the above must be introduced in England, before the manufacturer will encourage the Anglo-Merino wool; for after his purchase, when he thinks he has obtained sufficient allowance in the price to cover the waste, he is generally much disappointed in finding the loss in the manufacture so greatly to exceed his expectation, and he is deterred from making a second trial.

In the northern counties of England, and in Scotland, a practice has long prevailed of greasing the sheep with a mixture of tar and butter, to preserve the animal from the effects of moisture, and the inclemency of the weather in hilly and exposed situations. This practice seems at present peculiar to Britain, but the ancients evidently made use of mixtures of the dregs of olive wax, tar, wine, and other ingredients, to protect the skin of sheep after shearing, and to soften and improve the wool. Such was the practice of the Italian shepherds, as described by Virgil:

"Aut tonsum tristi contingunt corpus amurca,
Et spumas miscent argenti vivaque sulfura,
Idæasque pices et pingues unguine ceras
Scyllamque helleborosque graves nigrumque bitumen."
Georg. lib. iii.

That this practice was extremely beneficial in warm climates, by protecting the skin of the sheep from insects after shearing, and by keeping the wool in a soft state, cannot be doubted.

The practice of greasing the sheep in Scotland, and the northern counties of England, with a mixture of tar and butter, seems to have been introduced merely to preserve the sheep, and was generally supposed to be injurious to the wool. Indeed the great proportion of tar, too frequently employed, gave some ground for entertaining this opinion; and the breed of sheep, on which this mixture was most generally applied, is naturally the worst which exists in Britain for the production of wool, the fleeces more nearly resembling coarse hair than wool; but Mr. Bakewell, in his Treatise on Wool, observes, that "in Northumberland, where the fine-woolled sheep have received the benefit of greasing with a mixture in which the proportion of tar was merely sufficient to give it due tenacity, the wool is greatly improved by the process, but the ignorance or selfishness of the wool-buyers for a long time prevented the acknowledgment of the fact." Many were afraid to purchase the wool on account of its dirty appearance, but its value is now better understood in the Yorkshire markets, and it is purchased by the manufacturers of coloured cloth in preference to the ungreased wool of the same degree of fineness. The same preference is also given to the cloths in the halls, where they are sold in an undressed state. When these cloths are finished, their superiority is more apparent, possessing a degree of softness far beyond the ungreased wool. These wools appear to improve in every process of the manufacture, and yield a cloth of greater value by twenty or thirty *per cent.* than the ungreased hard wools, though the latter may be equally fine.

But even in Northumberland, where the wool is so greatly improved by the practice, its good effects in this respect are not sufficiently known, and the operation is delayed till the approach of winter. By this delay, the upper part of the staple which is first grown, is deprived of the advantage of being kept in a moist soft state during the summer heat. When the operation has taken place, a perceptible improvement may be observed in the wool which is afterwards grown. The line of distinction is clearly marked by the stain which the unguent leaves in the staple, the bottom part of which, where it is applied, is finer and softer than the upper part which was grown before its application. This difference is so great, that a careful examination of the fine-greased wools of Northumberland might alone be sufficient to demonstrate the advantage of the practice, and the inconvenience of delaying the operation to the end of the year. To derive the most advantage from the ointment both to the wool and the sheep, it should be applied immediately after shearing, and again at the approach of winter. By the first greasing, the wool will be kept soft and moist during the sultry heats of July and August, and the top of the staple would not become harsh and discoloured, which is frequently the case with English wool. One acknowledged advantage of greasing immediately after shearing should not be overlooked; it destroys the sheep-tick, and has a tendency to prevent cutaneous distempers, and to protect the skin from the bite of the fly. The manner of preparing the ointment in Northumberland is as follows:—From sixteen to twenty pounds of butter are placed over a gentle fire, and melted; a gallon of tar is then added, and the mixture stirred with a stick until the tar and butter are well combined, and form a soft tenacious ointment. Some skill is required in its application, the want of which has prevented the practice from prevailing more generally. If the ointment be rubbed on the wool, it collects on the top of the staple, where it detains the loose soil, and becomes hard, and is injurious to the wool. The proper method is to divide the staples or locks with one hand, and apply the ointment with the finger immediately upon the skin; it is thus kept constantly soft by the warmth of the animal, and is equally diffused through the fleece. Attention to this circumstance is of the greatest importance to the success of the practice. The quantity laid on each animal varies in different districts. In the lighter mode of greasing, one gallon of tar and twenty pounds of butter will be sufficient for fifty sheep. In Scotland, where greasing is applied merely to preserve the animal against the inclemency of the climate, a much larger portion of tar is used: this would be very injurious to the wool, were it of any other than the very coarsest kind.

Could a cheap substitute for tar be found, which would possess equal tenacity, the ointment might be applied with great advantage to all our native breeds of English sheep, both for the preservation of the animal and the improvement of the wool. Mr. Bakewell states, that long combing-wools, which have been greased in this manner, produce a softer and superior yarn to any ever made from wool of the native English breeds which have not undergone the pro-

ceſs. On all chalk and light calcareous ſoils, the wool is always much harſher than wools of the ſame degree of fineneſs grown on argillaceous or ſiliceous ſoils; and this ariſes from the calcareous earth penetrating the fleece, and abſorbing the natural greaſe, and thus rendering the fibres hard and elaſtic. Theſe ſoils cover a large portion of the ſouth-eaſtern counties of England, and of ſome of the mid-land counties; and it is well known to cloth manufacturers that the wool from theſe diſtricts do not work ſo well, nor make ſo ſoft a cloth, as wool on ſiliceous or argillaceous ſoils. Nor will this wool felt in the fulling-mill like the ſofter wools. The practice of greaſing would be of undoubted advantage in calcareous diſtricts, applying the ointment more ſparingly than in the northern counties. Perhaps twenty-five pounds of butter, and one of tar, or two of bees'-wax, might be ſufficient for one hundred South-Down ſheep; and if the mixture were applied once after ſhearing, and again in October, the expence would be abundantly compenſated by the improved condition both of the ſheep and wool. The ſoftneſs of wool appears to be eſſentially connected with the property of felting, and depends partly on the ſtructure of the ſurface of the fibre, and partly on its poſſeſſing but a moderate degree of elaſticity. The proceſs of felting is beſt illuſtrated in the hat manufacture, where the fibres of wool or fur are brought into contact by preſſure and warmth, and form a compact ſubſtance without the aid of ſpinning and weaving. In ſome parts of Tartary, coarſe cloth for tents is manufactured by ſpreading the wool on the ground, and preſſing it in warm water with the feet; this was probably the firſt mode of making cloth. All good woollen cloth is ſtill woven comparatively looſe, and is made firm and cloſe in the fulling-mill. The fibres of wool or fur have a tendency to move more eaſily in one direction when preſſed, than in the oppoſite direction. This motion has been compared to that of an ear of barley placed under the coat-ſleeve, with the points of the beards downwards; by the action of the arm the ear is moved in a retrograde direction, until it has advanced from the wriſt to the ſhoulder. When we draw a hair of wool or fur through the fingers in a direction from the points to the root, we can feel a ſenſible degree of roughneſs, which is not felt if the hair be drawn from the root to the point. Hence we may ſuppoſe, that the ſurface is covered with a number of points or rings, which are too minute to be obſerved by the microſcope, except in ſome kinds of fur, as in that from the South-ſea ſeal, in which, with a powerful microſcope, we have ſeen the ſurface covered with diſtinct leaves or points, ſhaped like thoſe of the artichoke. We have a ſtriking illuſtration of this tendency of the fibre to move in one direction in that particular proceſs of hat-making, where it is intended to cover the felt or ſubſtance of the hat with fur of a ſuperior kind. The felt on which this fur is to be laid being finiſhed, the hair of the beaver is uniformly ſpread upon the ſurface, and being covered with a cloth, it is preſſed and agitated by the hand for a certain time. The fibres of beaver-hair introduce themſelves by their roots into the felt, and proceed to a certain depth, and become firmly fixed in it. If the preſſure were continued for a longer time, the hairs would paſs entirely through the felt, going out at the under ſurface, as each hair follows the direction it acquired at the beginning of the proceſs.

As the felting property, therefore, ſeems to depend on the minute ſtructure of the ſurface of the fibre, it is eaſy to conceive how this may be injured by a dry calcareous ſoil, and how this property is beſt preſerved in thoſe furs which are grown under a covering of coarſe hair, and protected from external injury. The proceſs of greaſing is in ſome reſpects a ſubſtitute for ſuch a covering, and not only defends the ſurface, but prevents the fibre from becoming dry, harſh, and elaſtic. The ancient Greeks and Romans were in the practice of covering their ſoft-woolled ſheep, called *molles oves*, with ſkins: this has been ſuppoſed to have been intended merely as a protection from briars and underwood; but we have no doubt that wool ſo covered would be much ſofter than wool expoſed to the action of light, and of the ſoil. That the rays of the ſummer ſun have a tendency to make wool both coarſer and harſher, may be ſeen in the effect produced on ſheep that are expoſed to it without ſhelter immediately after ſhearing. The top point of the ſtaple which was grown at that time is almoſt always coarſer and harder than the bottom of the ſtaple which has been grown under the cover of the upper part of the fleece, and conſequently more protected from light. An analogous effect is produced on the ſkins of horſes kept in coal-mines, which become ſleek and ſoft. Theſe facts may ſuggeſt to wool-growers deſirous of improving their wool, the advantage of providing ſhade for their flocks during the ſultry heats of ſummer. The natural inſtincts of ſheep might teach them the impropriety, not to ſpeak of the cruelty, of keeping their ſheep in ſummer incloſed in pens, and unſheltered, upon a dry ſoil, where the animals are almoſt roaſted alive; a practice not leſs injurious to the health of ſheep than to all the beſt qualities of the wool. Next to a regular ſupply of food, protection from the effects of heat and wet are objects of the firſt importance in the management of ſheep; and it may be ſtated as an undoubted truth, that whatever contributes to the comfort of the animal, will enable it to fatten with a ſmaller quantity of food, will tend to preſerve it in a healthy ſtate, and will alſo increaſe the quantity and improve the quality of the wool.

WOOL, *Chemical Examination of*. The chemical properties of wool are very ſimilar to thoſe of hair, and as we omitted to ſpeak of theſe in their proper place, we ſhall introduce them here.

From the experiments of Achard and Hatchett, it appears that hair contains gelatine, to which it owes its ſuppleneſs and toughneſs. When hair is boiled in water, this principle is ſeparated, and the hair becomes much more brittle than before. Indeed, if the proceſs be continued long enough, the hair crumbles to pieces between the fingers. The portion inſoluble in water poſſeſſes, according to Mr. Hatchett, the properties of coagulated albumen.

Mr. Hatchett has concluded, from his experiments, that the hair which loſes its curl in moiſt weather, and which is ſofteſt and moſt flexible, is that which yields its gelatine moſt readily; whereas ſtrong and elaſtic hair yields it with the greateſt difficulty, and in the ſmalleſt proportion. This concluſion has been confirmed by a very conſiderable hair merchant in London, who aſſured him that the firſt kind of hair was much more injured by boiling than the ſecond.

Vauquelin has publiſhed a curious ſet of experiments on human hair of different colours. He found it completely ſoluble in a Papin's digeſter. During this proceſs, ſulphuretted hydrogen was evolved. The ſolution thus obtained contains a kind of bituminous oil, which is depoſited very ſlowly. This oil was black when the hair was black, but yellowiſh-red when red hair was the ſubject of experiment. When this oil was removed, nut-galls and chlorine produced copious precipitates. Silver was blackened, and acetate of lead precipitated brown. When concentrated by evaporation, it did not concrete into a jelly.

Water containing only four *per cent.* of potash dissolves hair, while hydro-sulphuret of ammonia is evolved. If the hair be black, a thick dark-coloured oil, with some sulphur and iron, remain undissolved. If the hair be red, this oil is yellowish. Acids throw down from this solution a precipitate, soluble in excess of acid.

Sulphuric and muriatic acids become red when first poured on hair, and gradually dissolve it. Nitric acid turns hair yellow, and dissolves it, while an oil separates, varying in colour, as before-mentioned, according to the colour of the hair employed. The solution contains a great deal of oxalic acid, besides bitter principle, iron, and sulphuric acid. Chlorine reduces it to a substance of the consistence of turpentine, partly soluble in alcohol.

Alcohol, digested on black hair, extracts from it two kinds of oil. The first, which is white, subsides in white shining scales as the liquor cools; the second is obtained by evaporating the alcohol. It has a greyish-green colour, and at last becomes solid. From red hair alcohol also extracts two oils, one white, as above, the other red as blood. After this latter has been extracted, the hair becomes chesnut. Hence its red colour appears to depend upon this oil.

Hair on incineration yields iron and manganese, sulphate and carbonate of lime, muriate of soda, and a considerable proportion of silica. The ashes of red hair contain less iron and manganese. Those of white hair still less; but in those we find magnesia, which is wanting in the ashes of other hair. The ashes of hair do not exceed .015 of the hair.

Hence, according to this analysis, hair consists of

1. Animal matters constituting the greatest part.
2. A white solid oil, small in quantity.
3. A greyish-green oil, more abundant.
4. Iron, state unknown.
5. Oxyd of manganese.
6. Phosphate of lime.
7. Carbonate of lime, very scanty.
8. Silica.
9. Sulphur.

Vauquelin infers from these experiments, that hair depends for its colour upon a kind of oil, which varies according to the colour of the hair in which it is found. He also supposes, that sulphuret of iron contributes to the colour of black hair. The sudden change of colour in hair from grief, he thinks, is owing to the evolution of an acid. Bichat, however, attributes this change, perhaps with greater probability, to the absorption of the colouring principle. To whatever cause it be owing, the fact appears undoubted; and it shews a closer connection between the living powers and the hair, than many physiologists are inclined to admit.

Wool appears, according to the experiments of Berthollet, to coincide almost exactly in its chemical properties with those of hair above-mentioned. When growing on the back of the animal, it is enveloped in a greasy matter, called the *yolk*, and which appears to be a kind of soap; or, more properly speaking, according to the experiments of Vauquelin, who has examined it, of

1. A soap of potash.
2. Carbonate of potash.
3. A little acetate of potash.
4. Lime.
5. A little muriate of potash.
6. An animal matter.

This substance appears to have the property of protecting the animal from insects to a certain degree, and of preserving the softness of the wool, which are perhaps its chief uses. It is removed from the wool before it is manufactured, by the process termed *scouring*. The affinity of the animal matter of wool for all colouring principles is very great, and in general far exceeds that of the different vegetable fibres, as cotton, flax, &c. for such principles. There is one kind of coarse wool, however, which, according to Dr. Bancroft, does not possess this property, and receives colours with great difficulty. See Dyeing, and the preceding article.

Wool, *Laws relating to.* The jealousy entertained on the subject of our wools, may be learnt from the legal restriction which has been made in relation thereto; as also with the view that as much employment as is possible may be found for the labouring classes. This is effected by the prohibition of the exportation of wool in an unmanufactured state, as will be seen below. It must be obvious, however, that it would be to little purpose to be thus strict respecting the article itself, if that which produced it was not equally guarded; therefore as early as 13 & 14 Ch. II. c. 18. it was made felony to export sheep from England or Ireland, or even to Scotland: now however the penalty is forfeiture of every ram, sheep, or lamb, and the vessel in which such is shipped with intent to exportation from Great Britain and the islands belonging thereto; and offenders are to forfeit 3*l.* for every sheep, &c. so shipped, and to suffer three months solitary imprisonment, and till the forfeiture be paid, but not to exceed twelve months; and for any second offence 5*l.* for each ram, &c. and six months imprisonment, and till the fine is paid, but not to exceed two years. 28 Geo. III. c. 38. § 2.

By the 9th and 37th sections, no wool, woolfells, mortlings, yarn, or worsted made of wool, woolflocks, coverings, cruels, waddings, or other manufactures, or pretended manufactures slightly wrought up so that it may be reduced to wool again, or mattresses, or beds stuffed with wool combed or fit for combing or carding, may be shipped or exported, or carried or moved for that purpose, from Great Britain, or Guernsey, Jersey, Alderney, Sark, or Man, to any foreign place, on forfeiture of the wool, with the carriage, ship, or cattle on which it is laden or removed; but 300 sheep may be sent annually from Liverpool or Whitehaven to the Isle of Man (51 Geo. III. c. 50.); and the person offending to forfeit 3*s.* for every pound weight, or 50*l.* in the whole, and to be imprisoned three months, and till the penalty is paid, but not to exceed six months; but for a second offence he is to forfeit the like sums, and to be imprisoned for six months, and till such fine be paid, not exceeding two years; but this is not to extend to lambskins dressed for furs and linings.

And persons qualified by the governors of the following islands may export the respective qualities set against them from Southampton to those places in every year:

		Tods.
To Jersey	- -	4000
To Guernsey	-	2000
To Alderney	-	400
To Sark	- -	200

28 Geo. III. c. 38. § 16, 17. And 20,000 pounds weight of worsted and woollen yarn may be exported annually from London to Lower Canada, by permission of his majesty in council. 47 Geo III. c. 9. 52 Geo. III. c. 55.

By the 48 Geo. III. c. 44. wool may be shipped in England for exportation to Ireland, on being duly entered and bond given for its true exportation there; and upon obtaining a licence under the hands of the commissioners of the customs to allow it.

No wool ſhipped to be ſent coaſtwiſe from one part of Great Britain to another, until due notice be given and bond entered into, and a licence obtained under the hand of three commiſſioners of the cuſtoms. Penalty, forfeiture. 28 Geo. III. c. 38. § 34. And wool muſt alſo be ſhipped coaſtwiſe in Britiſh ſhip, Britiſh owned and manned, the owner of which does not reſide out of Great Britain. § 19. and 12 Car. II. c. 18. Formerly there were penalties and forfeitures for keeping or removing wool in Kent and Suſſex within certain diſtances of the ſea (ten and fifteen miles), without entry and bond, and procuring certificates or permits, and alſo for removing wool within five miles of the ſea-coaſt of Great Britain before ſun-riſing and after ſun-ſet; but by the 54 Geo. III. c. 78. all the regulations formerly required *antecedent to the removal* of wool on land throughout England are repealed.

Wool to be packed in packs, or truſſes of leather, or canvas, called 'Pack-cloths,' or in linen or woollen, and to be marked '*Wool*,' in letters three inches long, on forfeiture of the wool, and 1*s.* *per* pound. 28 Geo. III. c. 38. § 28.

Perſons packing wool, &c. into boxes, barrels, caſks, or cheſts, and other than as above, or preſſing or ſteaning the ſame, to forfeit the goods, and 3*s.* *per* pound. Ibid. § 30, 31.

Inſurances for the conveyance of wool contrary to this act void, and the parties may be puniſhed. § 45, 46, 47, 48.

King's ſhips empowered and required to ſearch ſhips for wool ſhipped without licence. § 49, 50, 51.

No perſon can ſeize wool unlawfully removing but officers of cuſtoms, exciſe, and ſalt-duties, or perſons accompanied by a conſtable (§ 52.); and perſons neglecting their duty to forfeit 20*l.*, and making colluſive ſeizures or agreements to be ſubject to like penalties as exporters. (§ 53. 55.) Hindering, obſtructing, or beating officers, ſubjects offenders to tranſportation; and bribery of them, whether accepted or not, to the penalty of 300*l.* § 56, 57.

If any queſtion ariſes upon the growth of the wool, the *onus probandi* is to lie upon the owners. § 60.

Informations may be laid in any court of record, and penalties, &c. under 200*l.* may be determined before two juſtices of the peace; and juſtices at quarter-ſeſſions may direct ſhips, goods, wool, &c. to be ſold. § 62, 63.

Proſecutions to be commenced within three years. § 77.

Wool the growth of Ireland may be exported to England, and no where elſe. 1 W. & M. c. 32. 7 & 8 W. III. c. 28. 10 & 11 W. III. c. 10. 26 Geo. III. c. 11.

And the Admiralty is to appoint three ſhips of the ſixth rate, and eight or more armed ſloops, to prevent the exportation of wool from Ireland to foreign ports. 5 Geo. II. c. 21.

Wool the produce of any of the colonies, &c. in America, or countries on the continent of America, ſubject to any foreign European ſtates, imported into certain Britiſh Weſt India iſlands, may be imported into Great Britain under the regulations of the 12 Car. II. c. 18.

Thoſe places are, Jamaica, Granada, Dominica, Antigua, Trinidad, Tobago, New Providence, Crooked iſland, St. Vincent, Bermuda, Caicos, Tortola, Curacoa, and the Bahamas. 27 Geo. III. c. 27. 45 Geo. III. c. 57. 47 Geo. III. ſeſſ. 2. c. 34.

Britiſh hare or coney wool may not be exported, (except to Ireland, 39 & 40 Geo. III. c. 67.) on penalty of forfeiture. The owner or ſhipper to pay 100*l.*, and the maſter of the ſhip 40*l.* 24 Geo. III. c. 21.

Wool, *Cheeſe made under*, in *Rural Economy*, a term applied to that ſort of high-taſted ewe cheeſe which is made before the ſheep are ſhorn. See Cheese.

Wool, *Pack of*, a quantity of wool packed up cloſely together in a large bag of the ſack-cloth kind, which in London is conſtituted of two hundred and forty pounds. See Wool.

Woollen Manufacture

WOOLLEN MANUFACTURE, *Progrefs of the.* The origin of the woollen manufacture, like that of many other ufeful arts, is not precifely known. At a very early period, domeftic fheep were extenfively fpread over Weftern Afia. The introduction of fheep into Europe is not recorded by ancient writers, unlefs we fuppofe the expedition of the Argonauts to Colchis refers to this event. Sheep were probably firft domefticated for their milk, and afterwards for their fkins, which muft have been the firft drefs of paftoral nations. Sheep and goats, in the early ages of fociety, were nearly of equal value. The Greeks, who oftentatioufly refer all ufeful difcoveries to their own country, and rank their inventors among the gods, have afcribed to Minerva the invention of fpinning and weaving. Thefe arts appear, however, to have been firft practifed, at a very early period, in Egypt, and applied to the fpinning and weaving of flax. At what time they were firft applied to wool is unknown. Though Pliny informs us, that Nicias of Megara difcovered the art of fulling cloth, the property which wool poffeffed of felting was known in the Eaft at a much earlier period, and probably gave rife to the firft manufacture of woollen goods which were not woven, but felted like the fubftance of hats.

On this fubject, Mr. Luccock, in his Treatife on Wool, judicioufly remarks, "whilft the fkins of fheep dreffed with their wool on ferved as clothing, it is obvious that only one ufeful fleece could be obtained from one animal, and as the fleece is generally caft, or falls off once a year, this produce muft have been wafted. In a very early period, however, the property which wool poffeffes of felting was difcovered, or, in other words, it was found that by preffure and moifture the fibres of wool might be made to adhere together, and produce a compact pliable fubftance, quite as durable and more convenient than the fkins formerly ufed. This appears to have been the firft effort to produce a woollen manufacture." It is probable the felting property was difcovered by accident, as fome fleeces will felt upon the fheep's backs; among farmers, thefe are called cotted fleeces. When the application of this difcovery was firft made, the knowledge of the art was foon widely fpread. The tents of the Arabs and Tartars are, at the prefent day, all made of felt from the wool of fheep, mingled with the hair of goats, camels, and other quadrupeds, and may be confidered as remains of the original art of cloth-making.

The art of fpinning and weaving threads made from wool was, in all probability, derived from the Eaft; they are alluded to by Mofes as exifting nearly fifteen hundred years before the Chriftian era, and it appears that the early patriarchs had numerous flocks of fheep.

The greater part of thefe fheep, we are informed, were, at firft, either dark-coloured or fpotted; hence we may infer that the art of dyeing wool was then unknown. When the felection and cultivation of white wool gave to woollen cloth the property of receiving the tints of the dyer, the value and ufe of wool muft have greatly increafed, owing to the great eftimation in which richly-coloured garments are held by people advancing to a ftate of civilization.

Thus, in addition to the fuperior pliability and comfort of woollen cloth, compared with fkins or felts, the tafte for it muft have been widely fpread by the art of dyeing. It had alfo the great recommendation to its general adoption, that it could be fabricated with eafe in every family. The machinery required for the purpofe was extremely fimple. The diftaff and the loom, fays Mr. Luccock, were little more in the hands of the firft manufacturers, than the fpade in thofe of the hufbandman. Spinning and weaving, as we have already obferved, were in ufe at leaft fifteen hundred years before the Chriftian era; but the manner in which they were performed is not related until about three centuries afterwards. Then the loom confifted of a frame of wood, in fome refpect different from the modern one, but well adapted to the fame purpofes.

The alterations which have been made in it confift, perhaps, more in the pofition of the beam, and the mode of opening the web for the paffage of the fhuttle, than in any other circumftance. Nor was the earlieft mode of fpinning lefs perfect, than that which was practifed in the moft celebrated manufacturing countries for many ages afterwards. It was performed by means of a rod or ftaff, about which the wool to be fpun was carefully wrapt, and held in the left-hand, while a rough kind of fpindle, quickly twirled betwixt the right-hand and the thigh, was fuffered to continue its motion when fufpended by the thread which the artift gradually lengthened with his fingers. This leaft complex of fpinning-machines is not entirely laid afide even now. A few years fince it was not uncommon in the county of Norfolk, and its continuance in ufe through fo many ages is the beft proof of its excellence.

The preparing of wool for fpinning was probably firft effected by the fingers, and afterwards by the fuller's teazle or thiftle, the dipfacus fullorum, which with its rough and hooked points was well adapted to the purpofe, and has continued in ufe to the prefent day. The card afterwards ufed was probably a fubftitute for the carduus, or teazle. The application of the wheel to a fpindle, or the fpinning-wheel, is, we believe, unnoticed in hiftory. Whenever thefe inventions took place, it is probable their firft introduction contributed more to increafe the quantity, than improve the quality of the yarn and cloth. For a confiderable period after the commencement of the woollen manufacture, the improvements made in fpinning or weaving of wool were effected by the improved addrefs and fkill of the manufacturer, rather than by any alteration in his machinery, as we now fee the manufacturing nations of the Eaft execute very elaborate works with inftruments of the moft fimple conftruction. In proportion as luxury and refinement increafed, the demand for fuperior fabrics would induce the growers of wool to pay great attention to the fleece, and to felect and preferve for breeding thofe fheep which produced the fofteft and fineft wool; with the ancients thefe terms were fynonymous. The produce of fine white wool from fheep is entirely the refult of cultivation; it has never been grown except in countries were the woollen manufactures have flourifhed. The race of fine-woolled fheep has, however, been partly preferved in thofe countries after the deftruction of their trade. The grower would alfo foon learn to pay particular attention to the whitenefs of his fleeces, as a clear white ground is neceffary for receiving the moft brilliant dyes. Blue, purple, and fcarlet, were the tints moft admired; and though the ingredients, by means of which they were produced, are in fome meafure unknown, yet we have the moft indubitable teftimonies to their excellency, and the eftimation in which they were held. To produce them in their richeft

luftre, a felection of the wool moft adapted to receive them muft be made, and this would operate with great precifion upon the wool-forter's attention.

While the manufacture of wool was confined to the houfes of the grower, and the bufinefs of it tranfacted by his domeftics in a fecluded ftate, there was lefs room for the ftimulation and exercife of invention than in after-ages, when it became the appropriate calling of one particular part of the community, and their fuccefs depended upon the opinion which others formed of the fabric. Yet in the fimpleft days of Greece, it was not deemed an employment unfuitable to palaces, nor did a princefs degrade her dignity by fuperintending the labours of the loom, the diftaff, and the dyeing vat.

We have little information refpecting the woollen manufactures of the Greeks and Romans, as diftinct from their domeftic manufactures; but large eftablifhments were neceffary for the clothing of diftant armies, and for foreign commerce. That the Romans had carried the manufacture of fine woollen cloth to a high degree of perfection, is proved by a variety of circumftances, and particularly by the great attention paid to the cultivation of fine-woolled fheep, and by the high prices at which the wool and fheep were fold, as appears from the writings of Pliny, Varro, and Columella. Pliny defcribes two kinds of fheep: the one which grew coarfe long wool, and was on this account called *hirtum* or *hirfutum*, and from its hardinefs and ruder treatment *colonicum* or ruftic; the other breed was called *molle*, from the foftnefs of the wool, and *generofum* or noble, from its excellence; alfo *pellitum*, from its being clothed with fkins to protect the wool. The race is fometimes alfo called Tarentinum, Apulum, Calabrum Atticum, and Græcum, from the neighbourhood or diftrict in which it chiefly lived; but what is of more importance, as fhewing the origin of the fine-woolled fheep of Italy, the race is called Afianum; and, according to Pliny, a fimilar race exifted in his time at Laodicea in Syria. The defcription given of thefe fheep by Pliny agrees with the prefent race of Merino fheep. There is not, fays Dr. Parry, throughout Europe, any breed of fhort-woolled fheep now exifting befides the Merino, of which the males are horned and the females not.

That the Romans imported their Tarentine fheep into their weftern colonies, with the art of manufacturing fine cloth, we learn from Strabo and Pliny. The former writer, who flourifhed in the reign of Auguftus, fays, that in Turdetania in Portugal, then a part of Spain, "they formerly imported many garments, but now their wool was better than that of the Coraxi, and fo beautiful, that a ram for the purpofe of breeding was fold for a talent, and that fabrics of extraordinary thinnefs were made of this wool by the Saltratæ." Probably this was fimilar to the fhawl cloth of India, and woven in the fame manner, as Pliny calls it fcutulatus, a term which he applies alfo to the fpider's-web. The little attic talent of filver is eftimated to equal in value 216*l.* of Englifh money, which fhews the high eftimation in which the beft wool was held even in the colonies of Rome.

All ranks of people of both fexes among the Romans chiefly wore woollen garments. In the reign of Aurelian, 270 years after Chrift, a pound of filk, according to Vopifcus, was equal to a pound of gold. A people fo preeminent in wealth, and in all the refinements of art, would naturally be folicitous to attain the higheft degree of excellence in the manufacture of thofe fabrics, which were calculated to gratify their paffion for adorning their perfons, and it was equally as neceffary to confult their eafe as their vanity. The fummer-heat of Italy was fo great, that the affluent could fcarcely have fupported a woollen drefs, had it not been made of the lighteft and thinneft cloth. We find alfo, that during the Auguftan age, and for a confiderable time afterwards, it was the fafhion to wear cloths which, as at prefent, were furnifhed with a raifed nap or pile. Such cloths were called *pexæ*, in contradiftinction to tritæ or thread-bare. Thus Horace:

"—— Si forte fubucula pexæ
Trita fub eft tunicæ —— rides."

"You laugh if you efpy a thread-bare veft
Under a well-dreffed tunic."

And alfo Martial:

"Pexatus pulchre, rides mea, Zoile trita."

The term pexatus, applied to cloth, leads us to fuppofe that the nap or pile was raifed with a comb, having very fine teeth. Pliny informs us, that in his time the price of wool had never exceeded 100 feftertii the libra, or pound; now the Roman feftertius being about 8*d.* of our money, and the libra about 5245 grains, it follows that an avoirdupois pound, or 7008 grains, would have coft about 1*l.* 2*s.* of our money. From the intercourfe with Perfia and the Eaft, the Romans would become acquainted with the fhawl-cloths of India, and would naturally wifh to imitate fo beautiful and delicate a fabric. Thefe are made from very foft fine fhort wool, and not from combed wool, as has been generally fuppofed in this country. The exiftence of that manufacture in Hindooftan for many ages, is a proof of the high degree of perfection to which the fabrication of woollen cloth had been carried in former times. For fhawl-cloth is only woollen cloth, woven with a twill, and unmilled, but it is fpun to a great degree of finenefs, and from wool fo peculiarly foft, that it has never been rivalled by any European nations. The perfection of the colours, and the fkill difplayed in the weaving, we have no reafon to believe are greater now than in the time of Alexander the Great; and if thefe manufactures were fuccefsfully imitated by the Greeks or Romans, or even diftantly approached in the manufacture of their fine cloths, we may form fome idea of the perfection to which they had arrived. When in the decline of the Roman empire, their colonies were overrun by favage barbarians, all their public eftablifhments and manufactures were deftroyed, but the art of producing from the fleece a warm and fubftantial clothing was never entirely loft, even during the darkeft days of ignorance. It began to revive, and became the feparate occupation of one clafs of the community about the middle of the tenth century in the Low Countries, where it remained the glory of the people, and the fource of their opulence, through more than four hundred years. The wool which it confumed for the firft few years was the produce of their own paftures, which had but lately been reclaimed from the foreft; but as the manufacture extended itfelf, the demands became larger, and were fupplied from a greater diftance. The wealth which it diftributed was foon vifible, and people crowded into the country, engaged in its commerce, and pufhed their fpeculations with increafing vigour through a hundred and fifty years, when an inundation of the fea threatened to involve the art, the artift, and the country, in one general deftruction. The difperfion of the people who fled from the calamity which appeared to overwhelm their hopes, inftead of deftroying the infant manufacture, gave it additional vigour, and was the means of eftablifhing a connection be-

tween the Netherlands and foreign countries, which proved of the highest importance to commerce. It contributed to a much more speedy recovery of the arts connected with the woollen manufacture, from the ruin which seemed to threaten them, and gave a striking instance of their partiality for the seats where they have once flourished, under the patronage of a government liberal enough to encourage, and sufficiently powerful to protect them, even in situations attended with natural disadvantages. The influence of these manufactures upon the fleeces of the Low Countries must have been very considerable; for before the year 960 we have no reason to suppose that their quality was superior to that which we find in the neighbouring districts; yet it was not very long ere Flanders and Brabant became famous for the manufacture of fine cloths, even at a period when they imported but little foreign wool. Perhaps the fabrics might not be equal to those which we now produce from the fleeces of Spain, or even from the improved ones of our own sheep, but they were preferable to those of England and the nations of the continent, Italy and Spain excepted. It was about the year 1200 that the merchants began to import the wools of other countries, to extend their connections much more widely, and to grow by this means still more rich and powerful. The manufactures required a larger quantity of the raw material than usual, and the population of the country had reached that extent which does not admit of a great number of sheep being kept, even though the employment of the people depend upon the fleeces, and their subsistence upon the food which they furnish. We shall observe instances of a similar kind when we treat more particularly of England. The operation of these two causes was evidently sufficient to induce the manufacturer to go farther from home, and to seek the most convenient methods of supplying his looms. It might have been expected that he would have turned his attention to France and to Germany; but independent of the hostile dispositions of some of the neighbouring sovereigns, the raw material was too bulky to be conveyed at an easy expence through the bad roads of a half cultivated country; and the ships of Spain and of Britain, who found an interest in supplying the wants of the Netherlands, unladed their cargoes almost at his very door, and solicited in payment but little else than the goods which he had manufactured.

Spain was the first country on the western side of Europe, where the Tarentine breed of fine-woolled sheep were cultivated with success by the Romans. See Sheep.

This breed, intermixed with the native flocks, gave rise to the present fine-woolled sheep of Spain; and it does not appear that this valuable race was ever greatly neglected in that country. That it abounded in sheep in what is called the middle age cannot be doubted. At the period when the Saracens extended themselves in Spain, about the eighth century, to use the quaint words of Roderic, archbishop of Toledo, "it was fruitful in corn, pleasant in fruits, delicious in fishes, savoury in milk, clamorous in hunting, and gluttonous in herds and flocks,"—*gulosa armentis et gregibus*. He wrote in A.D. 1243. In England at that time sheep were so scarce, that a fleece was estimated at two-thirds the value of the ewe which produced it, together with the lamb.

Into Spain the invaders either carried the arts of luxury, or, what is more probable, improved them by their superior industry. The revenue of one of their sovereigns in the tenth century amounted to six millions sterling; a sum, says Gibbon, which at that time probably surpassed the united revenues of the Christian monarchs. When, several centuries afterwards, the Saracens were gradually expelled by their Christian neighbours, Spain saw nothing but the change of religion to compensate the loss of population, of agricultural and mechanical science, of industry, and wealth. On the recovery of the Seville from the Moors in 1248, not less than 16,000 looms are said to have been found in that city. Of these, the greater number was probably employed in the fabric of woollen cloths. According to Ustarix, "Theory and Practice of Commerce," the manufactures of Segovia flourished most, both in point of number and quality, and were in high esteem, being the best and finest that were known in ancient times. The temperature of the climate, and the luxurious propensities of the inhabitants, would naturally determine these fabrics to be of the lightest and softest kinds. Hence in the midst of the boasted ancient manufactures of England, we read only of two or three instances of the importation of English cloth into Spain. The Spaniards had certainly at that time their own native fleeces best adapted to their own taste and climate.

We are told by Dillon, in his "History of Peter the Cruel," that the woollen cloths of Barcelona were in high esteem in Seville in the reign of that prince, and in the preceding century. So far back as 1243, the woollen cloth of Lerida is spoken of in terms of great estimation. A few years after, Baurlas, Valis, Gerena, Perpignan, and Tortosa, were remarkable as manufacturing towns, and for the fineness of their cloths, fustians, and serges. So great was their exportation, that in 1353 there were 935 bales of cloth taken on board a ship from Barcelona to Alexandria by a Genoese privateer; and 1000 bales of cloth were taken on board three Catalonian ships in 1412, by Antonio Dorco, in the port of Callus. We are told by the same author, that, according to records still extant in Barcelona, considerable orders for wool were sent to England in 1446, in order to be manufactured there and returned to England in the form of cloth, the Spaniards themselves disdaining to wear it.

According to Lucius Marineus Siculus, who wrote in the time of the emperor Charles V., Spain was then full of herds and flocks, more especially it contained innumerable sheep; so that many shepherds, whom he knew, had flocks of 30,000 each; on which account Spain not only supplied its own people most abundantly, but also foreign nations, with the very softest wool.

This account is confirmed by what is related by Sandoval, who states, that in an insurrection in Spain in 1519, the army of insurgents, among whom were many cloth-workers, stipulated, among other points, that the cloths imported into Spain should be of the same size and goodness as those wrought there; and that the merchants and clothiers might have leave to seize, in order to work up, half the wools sold for exportation, paying the owners the price at which they had been bought. Hence we learn the superiority of Spanish cloth, and the great sale of Spanish wool to foreign countries at that time.

Damianus a Goes, who was page to Emanuel, king of Portugal, in 1516, has written a short account of the memorable things of Spain, which he dates at Louvain in the year 1541. In this work he says, that there are annually exported from Spain to Bruges 40,000 sacks of wool, each selling at the lowest for twenty gold ducats.

Now from an authentic acquittance, preserved in the Fœdera, from queen Elizabeth to Cosmo de Medici, for a sum borrowed by him of Henry VIII., we find that the gold ducat or florin was in 1545 equal to five shillings of our money. In this year, the 36th of Henry VIII., the base coinages began; but as queen Elizabeth seems to have continued receiving the instalments of the Florentine debt

for several years at the same rate, when the shilling was of something more than the present value, we think it probable that the rate was fixed at the beginning of the year 1545, when the shilling was at 1*s.* 1¾*d.* of our present coin. This wool was, therefore, worth at least 5*l.* 14*s.* 7*d.* the sack of 181½ lbs., and 11*l.* 9*s.* 2*d.* the sack of 364 lbs.

In 1560, in the time of Guicciardini, Spanish wool in the Netherlands was at a somewhat lower price. He tells us, "that they used formerly to send annually from Spain to Bruges more than 40,000 sacks, but that in this year the Spaniards, having made more cloth at home, had sent only 25,000 sacks, at 25 crowns each." The crown being 4*s.* and the shilling 1*s.* 0¼*d.* of our money, this would be 10*l.* 1*s.* 1*d.* the sack of 364 pounds. The depreciation seems in truth to have arisen from a diminished demand for this wool in the Netherlands. The wools imported into the Netherlands from Spain were the lower or coarser kinds.

The superfine wools of Spain seem to have been first introduced among the Italian states. Thus Damianus a Goes in 1541, after having specified the 40,000 sacks to Bruges, as before-mentioned, adds, "and also to Italy, and other cities of the Netherlands, are annually sent about 20,000 sacks, of which those used in Italy, being of the choicest wool, are sold at from forty to fifty gold ducats each."

From this account, we have a fair opportunity of drawing two important inferences: the first is, that the Spanish wool which went to the Netherlands was, as we have before observed, of the coarsest kind, being of only half the price of that which was exported to Italy; secondly, we can compare the value of the latter with that of our English wool, the best of which, according to the act of parliament in 1534, already quoted, did not in England exceed 5*s.* the stone of 14 pounds, of 6*l.* 10*s.* the sack of 364 pounds. The shilling, however, being then equal to 1*s.* 4½*d.* of our coin, increases the price of the sack 8*l.* 18*s.* 9*d.*; to which add custom and subsidy, 3*l.* 13*s.* 4*d.* or 5*l.* 0*s.* 10*d.*, and the result will be 13*l.* 19*s.* 7*d.* The additional charges of freight and merchant's profit would scarcely bring the whole amount to 16*l.* 16*s.* On the other hand, according to the testimony of Damianus a Goes, the Spanish sack of 181½ pounds was in 1541 worth 14*l.* 6*s.* 5½*d.*, and the sack of 364 pounds 28*l.* 14*s.* 6*d.* of our present money. If the author speaks only of the value of this wool in Spain itself, then a farther addition must be made of freight, merchant's profit, and probable duty to the crown. On the whole, this calculation is sufficient to shew in the strongest light the superior price of superfine Spanish wool, to that of the very best at that time produced in Britain.

Next in order of time to the Italians, the manufacture of superfine wool seems to have been adopted by the French, who, according to Guicciardini, in 1560 sent by land to Antwerp some very fine cloths of Paris and Rouen, which were highly prized.

It is probable, however, that these cloths were made only of mixed wool.

A strong confirmation of the early use of the best Spanish wool, unmixed with coarser by the Italian states, is furnished by Richelieu's Political Testament, printed in 1635, in which, speaking of the fine woollen manufactures of France, the author says, "the Turks prefer the draps de sceau de Rouen to all others, next to those of Venice, which are made of Spanish wool."

And the author of "England's Safety in Trade's Increase," written in 1641, tells us, that "the greatest part of their (the Venetians) wools from Spain, and the rest from Constantinople, is commonly brought in English shipping."

In 1646, Nicholas Cadeau and other Frenchmen had letters patent for twenty years, for making at Sedan black and coloured cloths, like those of Holland, of the finest Spanish wool.

The inhabitants of the north of Europe, as before-mentioned, were not at first able to manufacture fine Spanish wool, without the assistance of that which was longer and coarser. But what in the beginning was a matter of necessity, became afterwards an object of choice; and the more skilful clothiers, whether in Holland or elsewhere, either carding the finer and dearer Spanish with the coarser and cheaper English, or forming a warp of the latter, which they covered with a woof of the former, contrived to make a cheap and serviceable cloth, which pleased the eye equally well with the more costly fabrics of entire Spanish wool. This though generally concealed with great care at the time, yet is afterwards candidly acknowledged by writers actually engaged in the commerce of wool, and sufficiently refutes the prejudices which had here prevailed from the middle of the 16th to the middle of the 17th century. Hence it appears that our wool, when placed in connection with Spanish, was chiefly valuable from being well calculated not to improve but to adulterate it.

A treaty between France and Spain in 1659, enabled the former freely to obtain the wool of the latter, and thus to gain great advantage over us in the Levant trade. From the proximity of France to the woollen manufactures in the north of Spain, it might have been expected that the French would have earlier engaged in this manufacture; but owing to their frequent northern wars, and their attention being directed to the manufacture of silk, the French do not appear to have commenced the fabrication of woollens for exportation extensively before the 16th century. About this time, France made great progress in her manufactures of wool, and in securing the export trade, particularly that to Tartary, for which she was better situated than Holland or England.

The nature of her trade to warm climates directed her attention to the fabrication of finer and lighter cloths, than those made by her northern neighbours; in consequence of which she preserved the greater part of the Turkey trade to the period of the French revolution, and in general fine French cloths had attained a celebrity for their superiority, both in texture and dye, over those of any other country in Europe. The native breeds of sheep in France were greatly improved by intermixture with sheep imported from Spain. With these advantages, France might have nearly secured a monopoly of the finer branches of the woollen manufacture, had not the absurd policy of her rulers, in the revocation of the edict of Nantz, driven the manufacturing Protestants to other countries, where they contributed, by their exertion, their skill, connections, and capital, to form establishments which rivalled those of the country from which they were expelled.

Notwithstanding this, as France supplied the greater part of her own population of twenty millions with cloth, besides her foreign exports, we conceive that the woollens manufactured in that country, before the late revolution, equalled in quantity the cloth made in England at the time, and greatly exceeded it in value. Under the emperor Napoleon, the best Merino flocks were imported in multitudes from Spain, which have spread over the country, and are equal to supply extensively her manufactures of woollens, when they shall be again fully established. Considerable quantities of fine wool have been imported from France into England since the peace of 1815.

The confusion attendant on a great revolution, continued for twenty years, gave so severe a blow to the manufacturing establishments of France, that a considerable time must elapse before they are completely established. Prior to this revolution, the superfine cloths of France were superior to those of England, in texture, colours, and softness. In the finer articles of worsted goods, and in the mixed worsted goods made partly with long combing-wool, and partly with silk or goat's-wool from the Levant, they surpassed the manufactures of this country; but the manufacturers of the commoner kinds of worsted goods, as tammies and shalloons, could not rival us in foreign markets for want of a proper supply of wool suited to the purpose. The following were the principal seats of the superfine and fine woollen manufactures in France, arranged according to the different qualities of the goods made at each, beginning with the finest:

1. The manufactures of Gobelins.
2. Of Sedan.
3. Of Abbeville.
4. Of Louviers.
5. Of Elbœuf.
6. Of Rouen and Darnetal.

Besides several detached manufacturing establishments of superfine cloth in Languedoc, Champagne, and other parts of France.

At the Gobelins, superfine cloths of the very first quality were manufactured; but the manufactures there were confined solely to the broadest white cloth intended to be dyed scarlet or purple, and the brightest colours from cochineal.

Sedan followed next to Gobelins for the beauty of its superfine cloths, where they were also made of various breadths and colours.

Abbeville may be placed next after Sedan: some have even supposed that it equalled Sedan in the fineness of its cloths; but this arose from the cloths of the latter place being of various sorts: the lower kinds were certainly inferior to those of Abbeville; but the quality of the greater part of the cloths of Sedan were of a better kind than the average quality of the cloths of Abbeville. In the manufactures of Sedan, each manufacturer confined himself to a particular kind of cloth, for which he became distinguished, some being celebrated for fine, and others for superfine cloths exclusively; whereas in Abbeville, Louviers, and the other districts enumerated, there were manufacturers who made various sorts, and the proportion of the fine to the superfine was greater than at Sedan.

Elbœuf was one of the most ancient seats of the woollen manufacture in France, but the quality of the cloths made there had greatly degenerated from the years 1760 to 1770; but afterwards the manufacturers returned to the former quality of their cloths, which were partly made of the fine wools from Berry, and partly from fine Spanish wool, or from a mixture of Spanish with the best wools of Berry.

Rouen and Darnetal may be placed in the sixth class of manufacturing districts of fine cloth, in which the finest wools of France were principally used, mixed with those of Spain.

The establishments for the manufacture of common cloth and coarse woollens were much more widely spread over France. The goods appear to have been principally consumed in that country to supply the demand of a population of twenty millions, and the numerous military establishments, besides what might be sent to the French colonies.

As the French never exported any considerable quantity of common or coarse woollen cloths, the manufactures of these articles never equalled in extent those of England. The circumstance of the coarse cloth manufacture being so widely spread over the country, tended also to prevent that degree of rivalry which promotes the spirit of improvement where manufactures are more concentrated; add to this, the French had not that abundant supply of the coarser clothing-wools which could enable them to rival us in the export of heavy woollen goods.

The worsted manufactures of France, including serges and those goods made with a warp of worsted, were principally carried on in four of the provinces of France, but more extensively in Picardy than elsewhere. The long combing-wools which supplied this manufacture, were partly the produce of France, and partly imported from Holland, England, Flanders, and Germany. M. Rolland, in the French Encyclopædia, describing the French manufactures in the year 1783, soon after the American war, says, that during that war the English administration tacitly encouraged the exportation of wool to promote the interests of agriculture. He describes the French combing-wool as being coarser and more harsh than the wool of Holland, as wasting much more in the manufacture, and making goods of a very inferior quality. The combing-wools of England, though generally less sound and fine, and of a less pure white, than those of Holland, were particularly well suited to some parts of the worsted manufacture.

The combing-wools from Germany were coarse and harsh, and only used in default of other supplies. Very fine worsted yarn was also obtained from Saxony and the environs of Gottingen; but this yarn was tender, and required to be mixed with worsted yarn from English or Dutch wool. The yarn of Turcoign was supposed to be Dutch, but was principally from Flanders and Artois. The goat's-wool came from the Levant, by way of Marseilles, in bales of from 200 to 300 lbs. It sold from four livres to twelve livres *per* French pound; the price of that most generally used was about 4 livres 10 sous *per* pound. The silks used in silk camelots, &c. were obtained from Paris and Lyons.

The following table gives the quantity and value of wool yarns and worsted pieces in Picardy; but he supposes the quantity to be under the real amount, the manufacturers concealing the extent of their trade to avoid arbitrary taxation.

Wool consumed in the Worsted Manufactures of Picardy.

		sous.	livres.
French wool	3200000	at 22	3520000
Dutch ditto	180000	at 40	360000
English ditto	200000	at 32	320000
German ditto	100000	at 22	110000
	3680000		4310000

Yarn imported.

		liv. s.	
Yarn of Turcoign	60000	at 8 10	510000
German yarn -	100000	at 7 0	700000
Levant yarn, or mohair -	220000	at 5 10	1210000
Silk used in fine worsted goods	20000	at 35 0	700000
Total value of wool and yarn - -			7430000

Brought forward - -	7430000
Combing and ſpinning 3680000 lbs. of wool	4310000
Winding, warping, and weaving - -	4770000
Dyeing of yarn and pieces - - -	190000
Profit of the wool-dealers, manufacturers	1300000
Total value of 150000 pieces coming from the manufacturer - - -	18000000
Value of dyeing-wares - - -	500000
To which carriage and profit of the merchant and draper - - -	2000000
Total value of worſted goods in Picardy	20500000

One million and fifty thouſand pounds weight of wool were alſo conſumed in hoſiery in the ſame province, of which the greateſt part was native; and the remainder about two hundred and fifty thouſand pounds weight from Holland. The number of working manufacturers in Picardy is thus ſtated:

50000 men who gain	140 livres *per annum*		7000000
50000 women	70	-	3500000
150000 children	40		6000000

The greater part of the manufacturers reſided in the country, and were employed part of the time in agriculture; this was alſo the caſe with the manufacturers in the towns, ſo that not more than eight months in the year were devoted to manufactures. This change of employment, ſo conducive to the health and comfort of the labouring claſſes, may be regarded as preſenting the happieſt form under which manufactures can be carried on. This was alſo in a conſiderable degree the ſituation of the woollen and worſted manufacturers in Yorkſhire, before the late introduction of machinery had driven the population into large factories; a change which may be regarded as one of the greateſt evils that ever afflicted civilized ſociety, tending directly to degrade and enfeeble the human race, and to render man a wretched machine, a priſoner from the cradle to the workhouſe or the grave, devoid of moral feeling and phyſical energy.

What was the extent of the worſted manufacture in the other provinces of France where it was carried on, we have no correct means of aſcertaining. In the middle of the laſt century, the export of cloths and worſted goods from Languedoc alone amounted annually to about 60,000 pieces, ſent to the Levant and to Barbary. At that time alſo, Spain, and all the countries bordering the Mediterranean, received worſted goods from France. In the variety of worſted articles, in the ingenuity of the patterns, and the ſuperiority of the workmanſhip, as well as of the dyes, France may be regarded as having ſurpaſſed any other nation in Europe, prior to the year 1780, or about the cloſe of the American revolution. Since that period, the manufactures of England have aſtoniſhingly increaſed, and have obtained a decided preference in foreign markets.

The woollen manufactures of Saxony and Germany have been long eſtabliſhed; the fugitives from the edict of Nantz contributed much to improve and extend them. During the late war, all the manufactures in Germany and every part of the European continent ſuffered greatly, but are at preſent rapidly reviving, and will abridge the amount of our exports in Europe.

In Ruſſia, Sweden, and Denmark, the woollen manufacture, as a diſtinct occupation, is comparatively new; yet it has exiſted long enough to produce great alteration in their flocks. And as this change was attempted in a more enlightened period, and conducted by ſcientific men, the beſt means were adapted to promote the improvement, and new breeds of ſheep have been introduced into both countries. The ſame remark applies to Saxony and other circles of the German ſtates, and even Hungarian flocks are not without evident indication of a change for the better.

Of the worſted manufacture as diſtinct from the woollen, we have little information reſpecting its origin. It compriſes all thoſe goods made of combed wool in diſtinction from carded wool. We are unacquainted with the period when the wool-comb was invented, or when worſted goods were firſt manufactured. It is probable, that worſted goods were originally woven in the Eaſt, and that the knowledge of them was brought into Europe either by the Armenian merchants, or thoſe who returned from the extravagant expeditions which were undertaken for the recovery of the Holy Land from the dominion of the infidels. The garments which are now worn by the Turks, ſome of which ſeem to have been produced by means of the comb, the incidental mention of that inſtrument in an account which we have of Angora, and the demand for worſted goods through the Levant, confirm the conjecture, and lead us to ſuppoſe, that there exiſt very conſiderable manufactures of this kind in the Turkiſh empire, although we know little more of its domeſtic and rural condition, than can be obtained from the moſt vague accounts and uncertain deductions. After the art of ſpinning worſted yarn was known in the weſt of Europe, the looms of the Netherlands became active in converting it into thoſe peculiar kinds of goods to which it was adapted, and it ſeems as though the diſtinction between theſe and woollen articles was not generally noticed until ſome years afterwards. It might have been expected from the nature of the article, that the manufacture of worſted goods ſhould in many ſouthern countries have preceded that of cloth. Long-ſtapled wool ſuited to the comb ſeems more ſpontaneouſly the produce of uncultivated ſheep, than ſhort wool, which is to be manufactured by carding, and its mode of manufacture more nearly reſembles that of flax; hence it is not improbable, that worſted goods were made in Egypt and the Eaſt before the manufacture of woollen cloth. This is, however, uncertain.

In the manufacture of long wool, the fibres are arranged parallel to each other, like thoſe of flax; but before they are ſpun, they require to be laid even by ſome kind of inſtrument, which ſhall ſeparate the fibres, that they may draw out eaſily in ſpinning. A comb of a very ſimple conſtruction, with a few wires for the teeth, was probably firſt made uſe of. It was afterwards found, that the application of heat to the comb contributed more effectually to the regular arrangement of the fibres; and thus the invention of the common wool-comb aroſe, but at what period is unknown. Vulgar tradition aſcribes the invention to biſhop Blaize, who firſt uſed it in Alderney; but there does not appear any authority in ſupport of this opinion. The biſhop lived in Armenia, and was raiſed to the epiſcopal dignity about the time of Diocleſian, and ſuffered martyrdom under that tyrant. Before he was beheaded, he was tortured with iron combs, with which his fleſh was torn; and hence when an inſtrument of that kind was brought into common uſe, the workmen choſe him for their patron ſaint. The traditions of the origin and progreſs of the worſted manufacture are thus extremely imperfect; we ſhall have occaſion to ſpeak of its introduction and progreſs in this country in the following ſection.

Rise and Progress of the Woollen Manufactures in England. — The Romans, as we have stated on the authority of Camden, had a cloth manufacture at Winchester. The first account of any distinct body of manufacturers afterwards occurs in the reign of Henry I., but either the people of this country were wholly clothed in skins or leather in the intervening space, or, what is more probable, coarse cloths were manufactured in a rude manner in most of the towns and villages in England. A great part, however, of the dress of the labouring classes in the country was made of leather, particularly the breeches and waistcoats, even till the present reign. George Fox, the founder of the Quakers, in the reign of Charles I., travelled on his missions through the country, buttoned up in a leathern doublet, or waistcoat with sleeves, which supplied the place of a coat. This was not, as his adversaries afterwards affirmed, from any superstitious prejudice respecting that costume; it was the common dress of the labouring mechanics at that time, to which class he belonged.

The first account of any foreign weavers settled in England is recorded by William of Malmsbury and Giraldus Cambrensis, who relate that a number of Flemings were driven out of their own country, by an extraordinary encroachment of the sea in the time of William the Conqueror. They were well received, and first placed in the neighbourhood of Carlisle, and on the northern frontier; but not agreeing with the inhabitants, they were transplanted by Henry I. into Pembrokeshire. They are said to have been skilful in the woollen manufacture, and are supposed to have first introduced it into England as a separate trade. Cloth-weavers are mentioned in the exchequer accounts as existing in various parts of England in the reign of Henry I., particularly at London and Oxford. The weavers of Lincoln and Huntingdon are represented as paying fines for their guild in the 5th of Stephen; and in the reign of Henry II. (1189), there were weavers in Oxford, York, Nottingham, Huntingdon, Lincoln, and Winchester, who all paid fines to the king for the privilege of carrying on their trade. (Chronicon Pretiosum, p. 64.) There were also cloth dealers in various parts of Yorkshire, Norwich, Huntingdon, Gloucester, Northampton, Nottingham, and Newcastle-upon-Tyne; also several towns in Lincolnshire, and at St. Alban's, Baldock, Berkhamstead, and Chesterfield, who paid fines to the king that they might freely buy and sell dyed cloths. These are supposed to have been cloths imported from the Flemings. The red, scarlet, and green cloths, enumerated among the articles in the wardrobe of Henry II., were most probably foreign, as the English had attained little skill at that time in the art of dyeing. Madox's History of the Exchequer.

In the 31st of Henry II. the weavers of London received a confirmation of their guild, with all the privileges they enjoyed in the reign of Henry I.; and in the patent he directed, that if any weaver mixed Spanish wool with English in making cloth, the chief magistrate should seize and burn it. (Stowe's Survey of London.) This absurd edict was issued under the pretext of the inferiority of the Spanish wool, but was doubtless intended to encourage the growth of English wool, an article from which our kings derived a considerable revenue. The circumstance rather proves the superior excellence of Spanish wool at that time, and the jealousy which its importation had excited among the English wool-growers.

In the reign of Henry III. an act was passed limiting the breadth of broad-cloths, russets, &c. to two yards within the lists. In the year 1284, foreign merchants were first permitted to rent houses in London, and buy and sell their own commodities, without any interruption from the citizens. Previous to this date they hired lodgings, and their landlords were the brokers, who sold all their goods, and received a commission upon them. It was soon after pretended that the foreign merchants used false weights, and a clamour being raised against them, twenty of them were arrested and sent to the Tower. Amidst the numerous absurd restrictions to which commerce and manufactures were subjected, we need not be surprised at the little progress which they made.

The materials which history affords respecting the woollen manufacture before the reign of Edward III. are but scanty; it appears that the office of aulnager, or cloth inspector, was very ancient. In the reign of Edward I. we are informed by Madox, that Peroult le Tayleur, who held the office of aulnager of cloth in the several fairs of the realm, having forfeited it, the king, by writ of privy seal, commanded the treasurer to let Pieres de Edmonton have it, if he were fit for it, and a writ was made out accordingly, and he took the oaths of that office before the treasurer and barons. The facts above-stated prove the existence of the cloth manufacture in England before the time of Edward III., who is generally supposed to have first introduced the art into the kingdom. There is no doubt, that a new impulse was given to it during this reign by the liberal protection granted to foreign manufactures here: in all probability, they first introduced the manufacture of stuffs from combed wool or worsteds; an art requiring more skill, and more complicated processes, than are employed in the making of cloth.

In the year 1331, John Kemp, a master manufacturer from Flanders, received a protection to establish himself here with a number of dyers and fullers to carry on his trade, and in the following year several manufacturers came over from Brabant and Zealand. It is said, that the king's marriage with the daughter of the earl of Hainault enabled him to send over emissaries without suspicion, to invite the manufacturers to this kingdom. These manufacturers were distributed over the country, at the following places:—The manufacturers of fustians (woollens) were established at Norwich, of baize at Sudbury in Suffolk, of sayes and serges at Colchester in Essex, of broad-cloths in Kent, of kersies, in Devonshire, of cloth in Worcestershire and Gloucestershire, of Welsh friezes in Wales, of cloth at Kendal in Westmoreland, of coarse cloths, afterwards called Halifax cloths, in Yorkshire, of cloth in Hampshire, Berkshire, and Sussex, and of serges at Taunton in Devonshire. (Rymer's Fœdera, vol. i. p. 195.) Fresh supplies of foreigners contributed to advance the woollen trade of these districts.

Kendal, in Westmoreland, claims the honour of first receiving John Kemp, where his descendants still remain, and the woollen trade is at present carried on. In the following reign, we find the manufacturers of Kendal petitioning to be relieved from the regulations imposed on broad-cloths. Kendal green is mentioned by Shakspeare as an article of dress in the time of Henry IV., and there is reason to believe, that in the reign of Elizabeth, the woollen manufactures of that town were as extensive as at present.

In the year 1336, two woollen manufacturers from Brabant settled at York, under the king's protection: they are stiled in the letters of protection, "Willielmus de Brabant & Hanckcinus de Brabant, Textores." These persons probably laid the foundation of the woollen and worsted manufactures, which have since so extensively flourished in the western part of that county. It is not very improbable, that the manufacturer Hancks, called Hanckcinus,

gave the name to the ſkein of worſted, which is to this day called a hank.

The references which we have ſoon afterwards to the woollen manufacture, as exiſting in the diſtricts before-named, tend to confirm the belief, that the diſtribution of the foreign manufacturers we have given is correct. About this time, we learn that Thomas Blanket, and other inhabitants of Briſtol, ſet up looms in their own houſes, but were ſo haraſſed by the impoſitions of the mayor and bailiffs of the place, that they were obliged to obtain letters from the king to permit the free uſe of their trade, without impediment, calumny, or exaction. The letter to the mayor and bailiffs accuſes them in the following terms: "vos diverſas pecuniæ ſummas ab eiſdem Thomas et aliis exigitis et ea occaſione multipliciter inquietatis et gravatis, ut aſſerunt." Dr. Parry has conjectured, that blanket, which at firſt meant a coarſe white undreſſed cloth, derived its name from the ſame Thomas Blanket of Briſtol. The encouragement given to the woollen manufacturers during this reign, and the conſequent conſumption of wool at home, diminiſhed the export of it ſo much, that a duty was laid on cloth exported to ſupply the place. Blackwell-hall was appointed by the mayor and common council of London for the market, where cloth manufacturers might ſend their goods for ſale, in the year 1357.

In the courſe of the reign we find ſeveral other acts relating to the meaſurement and fulling of cloth, and the fees to be paid to the aulnager.

In order to form a more diſtinct idea of the relative value of wool, cloth, and other articles, after and before the reign, it may be proper to refer to the ſtate of the ſilver coinage.

	Grains.
The 28 Edward I. one ſhilling contained	264
18 Edward III. - - - - -	236
27 Edward III. - - - - -	213
9 Henry V. - - - - -	176
1 Henry VI. - - - - -	142
4 Henry VI. - - - - -	176
49 Henry VI. - - - - -	142
1 Henry VIII. - - - - -	118
34 Henry VIII. - - - - -	100
36 Henry VIII. - - - - -	60
37 Henry VIII. - - - - -	40
3 Edward VI. - - - - -	40
5 Edward VI. - - - - -	20
6 Edward VI. - - - - -	88
2 Elizabeth - - - - -	89
43 Elizabeth - - - - -	86

at which it continued to the preſent reign.

The following account of the exports and imports in the 28th of Edward III., ſaid to be found in a record of the exchequer, was publiſhed by Edward Miſſeldon, merchant, in the year 1623.

Exports.	£	*s.*	*d.*
Thirty-one thouſand ſix hundred and fifty-one ſacks and a half of wool, at ſix pounds value each ſack, amount to -	189,909	0	0
Three thouſand thirty-ſix hundred and ſixty-five felts at 40*s.* value, each hundred at ſix ſcore, amount to - -	6,073	1	8
Whereof the cuſtom amounts to - -	81,624	1	1
Fourteen laſt, ſeventeen dicker, and five hides of leather, after ſix pounds value the laſt, amount to - - - -	89	5	0
Whereof the cuſtom amounts to - -	6	17	6
Carried forward	277,702	5	3

	£	*s.*	*d.*
Brought forward -	277,702	5	3
Four thouſand ſeven hundred and ſeventy-four cloths and a half, after 40*s.* value the cloth, is - - - - - -	9,549	0	0
Eight thouſand and ſixty-one pieces and a half of worſted, after 16*s.* 8*d.* value the piece, is - - - - - -	6,717	18	4
Whereof the cuſtom amounts to - -	215	13	7
Summary of the out-carried commodities in value and cuſtom - - -	294,184	17	2

Imports.

	£	*s.*	*d.*
One thouſand eight hundred and thirty-two cloths, after ſix pounds value the cloth - - - - - - -	10,922	0	0
Whereof the cuſtom amounts to -	91	12	0
Three hundred and ninety-ſeven quintals and three quarters of wax, after the value of 40*s.* the hundred or quintal -	795	10	0
Whereof the cuſtom is - - -	19	17	0
One thouſand eight hundred and twenty-nine tons and a half of wine, after 40*s.* *per* ton - - - - - - -	3,659	0	0
Whereof the cuſtom is - - -	182	0	0
Linen cloth, mercury, and grocery-wares, and all other manner of merchandize -	23,014	16	0
Whereof the cuſtom is - - -	285	18	3
Summary of the in-brought commodities, in value and cuſtom, is - -	38,970	13	3
Summary of the impulſage of the out-carried above the in-brought commodities, amounteth to - - -	255,214	3	11

Admitting the correctneſs of this ſtatement, which we have no reaſon to doubt, we muſt obſerve, that the cloth imported was of a higher value *per* yard than the cloth exported. Hence it may be inferred, that for ſeveral years after the arrival of the Flemiſh weavers, we were partly dependent on foreigners for our fine cloths; the coarſer kinds then, as at the preſent day, forming the larger quantity of our exports. It is obvious alſo, that worſted goods had become an article of manufacture, nearly equal in importance with the woollen; and hence it is not improbable, that the greater part of the Flemiſh manufacturers were makers of ſtuffs and worſted goods, which was probably an entirely new trade in England.

The ſtatutes in the following reigns, relating to the woollen manufacture, prove the narrow and ſelfiſh policy by which the manufacturers were influenced: theſe ſtatutes refer either to reſtrictions which they wanted to impoſe, in order to confine the trade to themſelves, or are made to prevent them from fraudulently packing or weaving their goods. In conſequence of theſe fraudulent practices, the 13th ſtatute of Richard II. makes the following regulations, which are curious, as marking the ſpirit of the manufacturers, and alſo as proving the early eſtabliſhment of the woollen trade in the weſtern counties, where it now flouriſhes. It runs thus: "Foraſmuch as divers plain cloths, wrought in the counties of Somerſet, Dorſet, Briſtol, and Glouceſter, be tacked and folded together for ſale; of which cloths a greater part be broken, bruiſed, and not agreeing in the colour, neither according to the breadth, nor in no manner to the part of the ſame cloths ſhewed outwards, but falſely wrought with divers wools, to the great loſs and

damage of the people, insomuch that the merchants that buy the same, and carry them out of the realm to sell to strangers, be many times in danger to be slain, and sometimes imprisoned and put to fine and ransom. Therefore it is ordained, that no plain cloth tacked and folded shall be set to sale within the same counties." The same act permits certain cloths of coarse wool to be made of the breadth of three quarters, and appoints one weight and measure through the kingdom, except in the county of Lancaster. Another statute, in the same reign, allows every person to make cloth of what length and breadth he will, provided the aulnage and other duties are paid, and it be measured and sealed by the king's aulnager, and contain no deceit. The kinds of worsted goods which might or might not be exported, were also specified in this statute. During this reign it appears, notwithstanding the increase of our trade, that we annually exported about one hundred and thirty thousand packs of wool, paying a duty of one hundred and sixty thousand pounds.

In the 4th of Henry IV. the cloths made in London and the suburbs were ordered to have a seal of lead attached, and in a subsequent statute no cloths were to be folded before the aulnager had set his seal to them. In the following reign, the narrow cloths, called the dozens of Devonshire and Cornwall, are ordered to pay cocket customs, after the rate of broad-cloths.

In the reign of Henry VI. the exportation of woollen yarn is prohibited, and this prohibition seems to have been in full force when wool was allowed to be freely exported. The only reason assigned for this is, that the yarn paid no duty. During this reign two cloth-searchers were appointed for every hundred throughout the realm, who were to inspect and seal all cloth, taking one penny for each. This proves that the manufacture of woollens had spread over a great part of the kingdom. It is probable that this inspection extended to all cloths made in private families, which were sent to the fulling-mills.

The worsted trade was also increasing rapidly at this time: four wardens of worsted-weavers were appointed for the city of Norwich and two for the county of Norfolk, who were to make due search of worsteds, and of what length and breadth they were made. In the same reign it was ordained, that "if our woollens were not received in Brabant, Holland, and Zealand, then the merchandize growing or wrought within the dominions of the duke of Burgoine shall be prohibited in England, under pain of forfeiture." Hence we learn, that we very soon began to supply these same countries with woollens and worsteds, from which we had received workmen a century before.

In the third year of Edward IV. the woollen trade had increased so much, that the importation of woollen cloth, caps, &c. was prohibited. Woollen caps or bonnets were then universally worn; they were either knitted or made of cloth, and a large quantity of wool must have been consumed in their fabrication. About the year 1482, hats made from felts were introduced; but the manufacturers of caps, called the cappers, continued a powerful body a century afterwards. In the same reign, the wardens of worsteds at Norwich were doubled, or increased to eight.

The manufacture of fine broad-cloth must have been considerably improved about this time; for in the fourth of Henry VII. it was thought prudent to fix a maximum on the price of fine cloth, by which every retailer of cloth who should sell a yard of the finest scarlet grained cloth above sixteen shillings, or a yard of any other coloured cloth above eleven shillings, was to forfeit forty shillings *per* yard for the same.

In the year 1493, in consequence of a quarrel between Henry VII. and the archduke Philip, all intercourse between the English and Flemish ceased, and the mart for English goods was transferred from Antwerp to Calais. This interruption to the regular course of trade was severely felt by the woollen manufacturers. Lord Bacon, mentioning the renewal of the trade with Flanders, which took place again in 1496, says, "By this time the interruption of trade between the English and Flemish began to pinch the merchants of both nations very sore. The king, who loved wealth, though very sensible of this, kept his dignity so far as first to be sought unto. Wherein the merchant adventurers likewise did hold out bravely; taking off the commodities of the kingdom, though they lay dead upon their hands for want of vent." The merchant adventurers he describes as "being a strong company, and underset with rich men." It is not, however, very probable, that this company would continue to purchase goods without a prospect of gain. These merchant adventurers were divided into two bodies; those of London, which were the most powerful; and the merchant adventurers of England, who paid a fine to the former on all goods sold at the foreign marts.

In the reign of Henry VIII. the woollen trade, and particularly all kinds of worsted manufactures, appear to have been in a very flourishing state, though trade suffered several severe checks from the wars in which we were engaged. In the year 1527, Henry having entered into a league with France against the emperor Charles V., all trade with Spain and the Low Countries ceased. The goods sent to Blackwell-hall found no purchasers, the merchants having their warehouses filled with cloths; the poor manufacturers being thus deprived of employment, an insurrection took place in the county of Suffolk, where four thousand of them assembled, but were appeased by the duke of Norfolk. The merchants were summoned to appear before cardinal Wolsey, who in the name of the king reprimanded them in an angry tone for not purchasing the goods brought to market, and threatened them that his majesty would open a new mart at Whitehall, and buy of the clothiers to sell again to foreign merchants; to which menace one of them pertinently replied, "My lord, the king may buy them as well at Blackwell-hall, if it pleases him, and the strangers will gladlier receive them there than at Westminster."—"You shall not order that matter," said the cardinal; "and I shall send into London to know what cloths you have on your hands, and by that done, the king and his council shall appoint who shall buy the cloths, I warrant you." With this answer the Londoners departed. Grafton's Chronicle, vol. ii. p. 1167-8.

The interference of the cardinal raised the spirits of the manufacturers for a time, but originating in ignorance of the nature of trade, it could only have a temporary effect, and goods fell again till a truce between England and Flanders was made for the benefit of trade. This fact shews the dependance of England, even at that time, on the export of manufactured woollens. In this reign we find Lancashire and Cheshire first named as seats of the manufacture of coarse woollens; they are mentioned, together with Cornwall and Wales, as districts where friezes were made. It appears from various references, that Norfolk and Suffolk were then flourishing seats of the worsted manufacture, and of all goods made with a worsted warp. Wardens were allowed to the towns of Yarmouth and Lynn, but with a selfish restriction, that the pieces were to be dyed, spun, or callendered in the city of Norwich. In the last year of this reign, an act was passed to prevent any

persons besides woollen manufacturers, who bought wool for their own use, and merchants of the staple, who bought for exportation, to purchase wool with the intent to sell again. This act extended to twenty-eight counties, and secured a monopoly of the wool to the merchants of the staple, and to the rich clothiers. In the first year of the following reign, Edward VI., it was repealed, so far as to allow every person dwelling in Norwich and Norfolk, to buy wool the growth of that county, by themselves or agents, and retail it out in open market. The reason assigned is this: That almost the whole number of poor inhabitants of the county of Norfolk and city of Norwich had been used to get their living by spinning of Norfolk wool, which they used to purchase by eight pennyworth or twelve pennyworth at a time, selling the same again in yarn; and because the grower chose not to parcel it in such small quantities, therefore for the benefit of the poor, the wool of Norfolk was allowed to be purchased by wool-dealers. By this act, the 33d of Henry VIII., for prohibiting the exportation of yarn is made perpetual. The manufacture of woollens in the counties adjoining London appear to have been extensive, particularly in the county of Berkshire; for in the beginning of the reign of Henry VIII., John Winchcombe, of that county, commonly called Jack of Newbury, was celebrated as the greatest clothier in England. He kept one hundred looms in his own house, and in the expedition against the Scotch, he sent to Flodden-field one hundred men, fully equipped, at his own expence. Even so early as the 13th century, one Thomas Cole was distinguished by the name of the rich clothier of Reading, in Berkshire.

York, then the second city in the kingdom, and from its connection with the port of Hull well situated for the export trade, was probably an early seat of the woollen manufacture. We have already mentioned the settlement of two clothiers from Brabant in the time of Edward III. We do not learn precisely in our early historians, when the manufactures emanated from that city into the western parts of the county; but from an act in the 34th of Henry VIII. we are informed, that the chief manufacture of that city was the making of coverlets; the act recites, "that the poor of that city were daily employed in spinning, carding, dyeing, weaving, &c. for the making of coverlets, and that the same have not been made elsewhere in the said county till of late; that this manufacture had spread itself into other parts of the county, and was thereby debased and discredited, and therefore it is enacted, that none shall make coverlets in Yorkshire but the people of York." Thus we see, under the flimsy pretext of public benefit, the manufacturers were willing to disguise that selfish spirit of monopoly, which disgraces almost every page of our commercial history. The municipal regulations of the city of York, which were, and still continue to be, hostile to a free trade, probably obliged many manufacturers, who were not sharers in the monopolies of the guild, to establish themselves in the western villages of the county, where provisions were cheaper, and where they could carry on their trade without restriction. In the reign of Philip and Mary, soon after this period, we have the following interesting account of Halifax, in consequence of an act passed in the 37th of Henry VIII. to prevent any other persons than merchants of the staple and woollen manufacturers from buying wool in the county of Kent and twenty-seven shires. The poorer manufacturers, who were unable to lay in their stock of wool at one time, being hereby deprived of their trade, made application for redress, which was granted. The act recites as follows: "Whereas the town of Halifax being planted in the great waste and moors, where the fertility of the ground is not apt to bring forth any corn nor good grass, but in rare places, and by exceeding and great industry of the inhabitants; and the same inhabitants altogether do live by cloth-making, and the greater part of them neither getteth corn, nor is able to keep a horse to carry wools, nor yet to buy much wool at once, but hath ever used to repair to the town of Halifax, and there to buy some two or three stone, according to their ability, and to carry the same to their houses, three, four, or five miles off, upon their heads and backs, and so to make and convert the same either into yarn or cloth, and to sell the same, and so to buy more wool of the wool-driver; by means of which industry, the barren grounds in those parts be now much inhabited, and above five hundred households there newly increased within these forty years past, which now are like to be undone and driven to beggary by reason of the late statute (37th of Henry VIII.) that taketh away the wool-driver, so that they cannot now have their wool by such small portions as they were wont to have, and that also they are not able to keep any horses whereupon to ride or fetch their wools further from them in other places, unless some remedy may be provided. It was therefore enacted, that it should be lawful, to any person or persons inhabiting within the parish of Halifax, to buy any wool or wools at such time, as the clothiers may buy the same, otherwise than by engrossing and forestalling, so that the persons buying the same do carry the said wools to the town of Halifax, and there to sell the same to such poor folks of that and other parishes adjoining, as shall work the same in cloth of yarn, to their knowledge, and not to the rich and wealthy clothier, or any other to sell again. Offending against this act to forfeit double the value of the wool so sold."

From this we learn that many woollen manufacturers had been either driven from York at an early period, by the oppression of the municipal regulations, or had retired where provisions were cheaper, and where they had better streams for the erection of fulling-mills, and for other processes of the manufacture, such as dyeing and scouring.

The woollen manufactures also gradually retired from the vicinity of the metropolis, owing to the increased price of provisions and labour, and probably also to the difficulty of obtaining commodious streams for the scouring and fulling of cloth, when the country round London became more populous. In the latter part of the reign of Henry VIII. we are informed, that the king demised to William Webbe the subsidy and aulnage of all cloth made in the county of Monmouth, and in the twelve shires of Wales. A former act of this reign, speaking of the manufacturers of North Wales, says, they had been used to sell their cloths so craftly and hard rolled together, that the buyer could not perceive the untrue making thereof. These acts prove the extension of the woollen manufactures westward.

In the same reign, an act mentions the woollen manufactures as being established in Worcestershire, but prohibits any one from making cloth in the county, except within the city of Worcester, and in the towns of Evesham, Droitwich, Kidderminster, and Bromsgrove; and forbids the owners of houses in those places from letting them at advanced prices to the cloth-manufacturers. The woollen manufacture has continued to the present day at the two last of these towns. In the reign of Edward VI. Coventry and Manchester are mentioned as manufacturing places. The manufacturers in the old established seats of the woollen trade appear to have been greatly alarmed at the extension of the cloth manufacture, and to have exerted all their influence to restrain it. Near the conclusion of the reign of

Philip and Mary, an aƈt in 53 feƈtions was paffed, relating to the making of woollen cloths. It enaƈts, that no perfon fhall make woollen cloth but only in a market-town, where cloth hath commonly been ufed to be made for the fpace of ten years laft paft, or in a city, borough, or town corporate. From this reftriƈting aƈt, however, the following exceptions are made: to all perfons who dwell in North Wales or South Wales, Chefhire, Lancafhire, Weftmoreland, Cumberland, Northumberland, the bifhopric of Durham, Cornwall, Suffolk, Kent, the town of Godalmin in Surrey, or in Yorkfhire, being not within twelve miles of the city of York, or any towns or villages near the river Stroud in Gloucefterfhire. This aƈt, fo abfurd and oppreffive, was obliged to be modified in the firft year of the following reign, by an aƈt entitled "An Aƈt for the continuing and making of Woollen Cloths in divers Towns in the County of Effex." Bocking, Watherfold, Cockfhill, and Dodham, are the towns fpecified.

In confequence of the increafe of our manufaƈtures, the export of wool had nearly ceafed before the reign of Elizabeth; and a confiderable advance appears to have taken place in the price of food, clothing, and rents. The export trade of England was carried on very extenfively by three companies of merchants, the merchants of the Stillyard, who were foreigners, the merchants of the Staple, and the merchant adventurers, who were Englifh. See Stillyard, Staple, and Adventurers.

The merchants of the Stillyard were of ancient ftanding, and were originally from the Hanfe towns: they had great privileges granted them, and particularly they were allowed to export and import all wares and merchandize, on payment of the fmall duty of one and a quarter *per cent.* This gave them a decided advantage over the other companies; and it is alleged that they lent their name to cover the import and export of goods belonging to private merchants, and thereby evaded the regular duties on fuch goods. This company had engroffed a confiderable part of the cloth trade. In the year 1551 they exported 44,000 cloths; foon after which this company was diffolved. The merchant adventurers fucceeded to that branch of their trade: according to the account of John Wheeler, fecretary to the company, there were annually fhipped by them 60,000 white cloths, worth 600,000*l.*, and 40,000 cloths of all forts, baizes and kerfies, worth 400,000*l.*, befides wool and woolfels. We are told by Camden, that, in this reign, the commerce between England and the Netherlands rofe to above twelve millions yearly, and the woollen trade alone amounted to five millions. The Latin terms which Camden employs, *milliones aureorum*, leaves the amount intended uncertain: if we fuppofe it to be ducats, the quantity is much greater than England exported at that time; probably florins were intended, which makes the amount about 750,000*l.*

Befides the exports to Antwerp, Englifh cloth was at this time fent to Amfterdam, Hamburgh, Sweden, Ruffia, and other countries. The woollen trade of England had now advanced to a higher ftate of profperity than at any former period; and from this time it appears to have declined until after the revolution of 1668. In this reign, the price of wool, which we believe to mean long or combing wool, had advanced from 13*s.* 4*d.* to 22*s.* *per* tod; and the fhilling containing the fame weight of filver as our late coinage, *viz.* 86 grains, the relative value of a tod of long wool was confiderably more than it has ever been during the prefent reign.

The declenfion of our manufaƈtures in the fucceeding reigns of the Stuarts, as we have reafon to believe, extended much more to woollen cloths than to worfted pieces. Long wool, or combing-wool, was more the peculiar produce of England than clothing-wools. The latter were grown in abundance, and of a fuperior quality, in Spain, Portugal, and France; but the combing-wools of England, on account of the fuperior foundnefs of the ftaple or fibre, and the quantity fupplied, gave a decided advantage to our manufaƈturers of ftuffs or worfted pieces.

The perfecution of the Proteftants by the duke of Alva in the Netherlands drove multitudes of the manufaƈturers into England, where they were gracioufly received by Elizabeth, who gave them liberty to fettle at Norwich, Colchefter, Sandwich, Maidftone, and Southampton. Thefe refugees contributed to extend our manufaƈtures of worfted goods and light woollens, called bays and fays; they alfo introduced the manufaƈture of linens and filks, and it is fuppofed that they firft taught the art of weaving on the ftocking-frame.

In the latter part of the reign of Elizabeth an aƈt was paffed to relieve the counties of Somerfet, Gloucefter, and Wiltfhire, from thofe abfurd and oppreffive ftatutes which confined the making of cloth to corporate towns. This aƈt, which gave to all perfons refiding in thefe counties the privileges of free trade, could not fail to extend and eftablifh the woollen manufaƈtures in thefe parts, and they have remained to the prefent time the principal feats of the fuperfine cloth trade, whilft many manufaƈturing corporate towns, which were then flourifhing, have funk to decay. Various aƈts, regulating the length, breadth, and tentering of woollen goods of different kinds, were alfo paffed in this reign, referring to the counties of Oxfordfhire, Devon, and the counties north of Trent, particularly Yorkfhire and Lancafhire. The importation of foreign wool-cards was alfo prohibited. The aƈt recites, that many thoufands of woollen card-makers and card-wire drawers, living in London, Briftol, Gloucefter, Norwich, Coventry, and elfewhere, had heretofore fubfifted themfelves and families upon that bufinefs, which was now greatly impaired by the importation of wool-cards. No laws prohibiting the export of wool were thought neceffary in this period of our hiftory, and it continued to be exported during the whole of this reign, as appears by the account of the merchant adventurers, who exported it together with cloth; but though wool was freely exported, an aƈt was paffed to prevent the carrying of live fheep, lambs, or rams out of England; but the reafons for this aƈt are not recited, though it ftates it was for divers good caufes and confiderations. The internal tranquillity that the country enjoyed during this long reign, the influx of foreign makers of new kinds of worfteds, and other articles not known before, the opening of a new trade to Turkey and the Barbary ftates, by treaty in the year 1579 and in 1585, all greatly contributed to the extenfion of the woollen trade and manufaƈtures. There were indeed other circumftances which muft have operated againft our manufaƈturers in part of this reign. The interruption of commerce between England and the Netherlands in 1564, which lafted fome time, the wars with Spain, the facking of Antwerp, in which the Englifh merchants fuffered feverely, gave a confiderable check to the foreign trade; yet we have feen that the merchant adventurers alone exported woollens to the amount of one million fterling towards the latter end of this reign. The demand at home for woollens muft alfo have greatly increafed during the long period of domeftic tranquillity which the nation at that time enjoyed, and particularly from the prevailing tafte for coftly dreffes which has fpread from the court through the country.

A great part of our woollen exports hitherto confifted of white undreffed cloth; but in the following reign of James I. it was reprefented as bad policy to permit the exportation of cloth in this ftate, and thereby lofe the profit on the

dyeing and finifhing. A letter exifts addreffed to king James on this fubject, afcribed to fir Walter Raleigh, but without fufficient evidence, as "the moft ancient manufcripts of this letter in the libraries of the nobility afcribe it to John Keymer." (Oldy's Life of Sir W. Raleigh.) In this letter it is ftated, "that there have been eighty thoufand undreffed and undyed cloths exported yearly, by which the kingdom has been deprived of four hundred thoufand pounds for the laft fifty-five years, which is nearly twenty millions that would have been gained by the labour of the workmen in that time, with the merchants' gains for bringing in dyeing-wares, and return of cloths dreffed and dyed, with other benefits to the realm." The writer proceeds, in another part, to ftate, that there had alfo been exported in that time annually, of baizes and northern and Devonfhire kerfies, in the white, fifty thoufand cloths, counting three kerfies to a cloth, whereby had been loft about five millions to the nation in labour, profit, &c. The author informs us, that the baizes fo exported were dreffed and dyed at Amfterdam, and fhipped to Spain, Portugal, and other kingdoms, under the name of Flemifh baize, fetting their own feal upon them; "fo that we lofe the very name of our home-bred commodities, and other countries get the reputation and profit thereof." The author concludes with affertíng, that the nation lofes a million a year by the export of white cloths, which might be dreffed and dyed as well at home. This letter has been often quoted as containing unanfwerable reafons for confining the whole procefs of the cloth manufacture to our own country; but, like other monopolifts, the writer feems to forget that there are two parties in all mercantile tranfactions, and that manufactured goods muft be fent in that ftate in which the purchafer is willing to receive them, unlefs it be proved that he cannot procure them elfewhere. Let us mark the refult. Alderman Cockayne, and other London merchants, had fufficient influence with the government to obtain the prohibition of the export of white cloths, and to fecure a patent for dreffing and dyeing of cloths. In confequence of which, the Dutch and Germans immediately prohibited the importation of dyed cloths from England, which gave fo great a check to our export trade, that in the year 1616, the whole amount of cloths exported of every kind amounted only to fixty thoufand, fo that the export trade in woollens had fallen to lefs than one-third of its former amount; and in the year 1622,

	l.	*s.*	*d.*
All our exports of every kind amounted only to	2,320,436	12	10
Whilft our imports were	2,619,315	0	0
Leaving a balance againft us of	298,878	7	2

It being from experience proved, that the policy of dreffing and dyeing all our goods at home had produced the greateft injury to the woollen trade, the reftrictions were taken off, and the export for white cloth left free. In the former reign, cloths about four pounds value were, by ftatute, to be fent out dyed, by all perfons except the company of merchant adventurers, who obtained a licence to export all forts of white cloths; and though this was itfelf a monopoly, yet, as it gave foreigners an opportunity of receiving our finer cloths in the ftate which they moft wanted, it was the means of increafing our trade: indeed it is faid by Miffelden, that "within a few years after granting this licence, the vent for cloth in foreign parts increafed to twice as much as it had been during the ftrict obfervance of the ftatute." With this fact before their eyes, it is fcarcely poffible that our ftatefmen at that time could have proceeded to the prohibition of white cloth exports, unlefs they had been (as was afferted) influenced by prefents from alderman Cockayne and the rich merchants, who expected to receive the benefit arifing from the prohibition, and the exclufive right of dyeing and dreffing. The wool-growers equally felt the ill effects of this prohibition. Wool is faid to have fallen from thirty-three fhillings *per* tod to twenty fhillings; if by this is meant the long combing-wools, the former price, confidering the value of money at that time, is much higher than it has been in the laft or the prefent century.

During the reigns of the Stuarts, the infamous policy they adopted ftruck not only at the liberty, but at the commercial profperity of the country. Archbifhop Laud, imbued with the malignant zeal of a bigot, commenced his attacks on the defcendants of the French Proteftants, eftablifhed as manufacturers of woollens in Norfolk and Suffolk, from which counties his perfecuting fury drove fome thoufand families. Many of them fettled in New England; but others went into Holland, where they were encouraged by the Dutch, who allowed them an exemption from taxes and rents for feven years. In return for this, the ftates were amply repaid by the introduction of manufacturers, with which they were before unacquainted. In the year 1622, king James iffued a proclamation to prohibit the exportation of wool, fuller's-earth, &c. In 1640 wool was again admitted to be exported on the payment of certain duties; and we are told, that in the fame year fir John Brownlowe, of Belton in Lincolnfhire, fold three years' wool at twenty-four fhillings *per* tod to a baize-maker of Colchefter. As it is reafonable to fuppofe that this was the long combing-wool of that county, it fhews the high relative price of the article at that time. In 1647, owing to the high price of wool, its exportation was again prohibited.

During the civil wars, the manufactures and export trade of England declined, and the Dutch availed themfelves of this to extend their own manufacture and export of woollens, particularly to Spain, from whence they brought fine Spanifh wool. At this time it appears, that the woollen manufactures in Poland and Silefia were rapidly increafing; and the Englifh government received information that two hundred and twenty thoufand cloths were made there annually, befides confiderable quantities made at Dantzic, and in the vicinity.

The duke of Brandenburg, it was alfo ftated to our government, had ordered one hundred thoufand ells of Silefia cloth at Köningfberg for his troops, which had been heretofore fupplied with Englifh cloth. The eftimation in which our cloth had been held is faid to have been loft by negligence in the manufacture, particularly in the fpinning and weaving. The Dutch and Poles had a little before this time received a great number of Proteftant manufacturers, who fled from the perfecution of the duke of Alva in Brabant and Flanders.

Here it may be proper to remark, that the Englifh as a nation had little intercourfe with other parts of the world, except through a few large trading companies: hence they were extremely ignorant refpecting the ftate of foreign countries, and fuppofed that the cloth trade had been confined to their own country for three hundred years; and they confidered the eftablifhment of other manufacturers as a novelty and infringement of their juft rights. With thefe views, it was propofed to obtain a complete monopoly of all the clothing-wools in Spain, in order to prevent the Dutch and other nations from rivalling our manufactures. This is the more extraordinary, as the Englifh had not then learned, like the Dutch, to manufacture Spanifh wool, without mixing it with that of their own country. It is needlefs to fay, that

the negociation of ſir William Godolphin for this ſelfiſh monopoly of wool was not ſucceſsful. During the whole reign of Elizabeth, when our woollen manufactures were in the higheſt ſtate of proſperity, wool and woolfels were permitted to be exported. In the reign of James I. and Charles I., when the trade was declining, proclamations were iſſued to prevent the exportation of wool, and alſo that of fuller's-earth. During the commonwealth, an ordinance of parliament was iſſued to prohibit the exportation of wool and fuller's-earth, on pain of forfeiture of the wool, and a penalty of 3*s. per* pound on every pound of fuller's-earth. The firſt act of parliament which abſolutely prohibited the exportation of wool by making it felony, and which could not be ſet aſide by a royal licence, is the 12th of Charles II., which was paſſed ſoon after the Reſtoration.

The grounds of this meaſure are ſtated in the preamble of the act: "For the better preventing the loſſes and inconveniences which have happened by and through the ſecret and ſubtile exportation of wool out of the kingdom; and for the better ſetting to work the poor people and inhabitants of the kingdom, to the intent that the full and beſt uſe and benefit of the principal native commodities of the kingdom may redound to and be unto and amongſt the ſubjects and inhabitants of the kingdom, and not unto any foreign ſtates." Previous to this time, the proclamations and ordinances iſſued to prevent the exportation of wool, for the moſt part, ſignified nothing more than the impoſition of a duty or a compoſition for exporting by licence from the government, what on other terms was forbidden, under penalties of confiſcation, fine, or impriſonment. We have ſeen that, from the death of Elizabeth to the Revolution in 1688, the woollen trade was generally in a languiſhing ſtate. In the year 1665, Thomas Telham of Warwickſhire, with two thouſand manufacturers, left the kingdom, and eſtabliſhed themſelves in the Palatinate, and commenced a woollen manufacture there, and were greatly encouraged by the elector. The eſtabliſhment was ſoon afterwards joined by a number of manufacturers from Hertfordſhire.

During the period from Elizabeth to the year 1668, the Engliſh appear to have made no improvement whatever in their modes of manufacture of woollen cloth, whilſt the neighbouring nations had been making a gradual progreſſion, both in the ſtyle of their manufacture, and the amount annually produced. It was eſpecially in the manufacture of fine cloths that their ſuperiority was manifeſt. The Dutch, in particular, were far more expert than the Engliſh in the dreſſing and dyeing of cloth. This will appear from the following remarkable fact ſtated by Coke, vol. ii. p. 169. In the year 1668, one Brewer, with about fifty Walloons, who wrought and dyed fine woollen cloths, came into England, and received the royal protection and encouragement. By him the Engliſh were firſt inſtructed how to manufacture cloth of the beſt Spaniſh wool, without any admixture with inferior wool; and alſo to manufacture and dye fine cloths cheaper by 40 *per cent.* than they had done before. Ten years before this time, it had been publiſhed and admitted in England, that "Spaniſh wool alone could not be wrought into cloth." It may ſeem truly extraordinary that the Engliſh, who had ſo long carried on the manufacture of woollen cloth, had not availed themſelves of the revolution in Flanders, which drove away the beſt maſter manufacturers, to encourage their ſettlement in this country. M. Huet explains the fact in a way which is not very creditable to the liberality of the Engliſh manufacturers, or to the wiſdom of our inſtitutions. "It was owing to the municipal laws of England, and its uſages towards ſtrangers; who, beſides being doubly rated at the cuſtom-houſe, were excluded from all companies or fraternities of trade; and were not allowed to carry on manufactures as maſters or partners, unleſs ſuch as the natives were unacquainted with; ſo that none of the Flemiſh maſter manufacturers of fine cloth went thither (to England), their's being a myſtery not accounted new, though very much ſuperior to the cloth working then known in England. It was only thoſe who wrought in new kinds of worſteds, ſerges, damaſks, or ſtockings, who went thither. The ſame policy was alſo adopted by the Hanſe towns: hence the greater part of the vaſt and profitable trade, which was loſt to Antwerp, centered neceſſarily in Holland, where the manufacturers from Brabant were cordially received." This appears a ſatisfactory explanation why the Engliſh, in 1668, were ſo much inferior to the Dutch in the manufacture of fine cloth.

In the year 1660, however, our manufacturers began to be aware of the ſuperiority of Spaniſh wool, and to mix it with the beſt Engliſh, probably in what were called medleys or mixture-cloths, or elſe employing the Engliſh wool for warp, and covering it with weft of Spaniſh wool. The beſt Spaniſh wool was then 4*s.* and the ſecond ſort 3*s. per* pound, and the beſt Engliſh 1*s.* 6*d. per* pound.

It is deſerving of notice, that, in the latter period of the Commonwealth, our trade is ſaid to have greatly revived, but to have ſuffered a miſerable depreſſion almoſt immediately after the reſtoration of Charles II. In a letter of M. Downing of the Hague to the preſident of the council in London, 1660, printed in Thurloe's State Papers, vol. vii. p. 848. it is ſtated, that great quantities of wool were brought ſecretly from England to Holland; and he adds, that the Dutch had at that time got in a great meaſure the manufacture of fine cloth, and would probably, with Sileſia, engroſs alſo the manufacture of coarſe cloth, and leave England nothing but its native wool to export.

In the year 1662, great complaints were made againſt the merchant adventurers for their neglect of the cloth trade; in reply to which they ſaid, that the demand for Engliſh cloths failed in the foreign markets, the white clothing trade having abated from 100,000 cloths annually to 11,000. In the year 1663 our whole exports were only about two millions, and our imports four, leaving a balance of two millions againſt this country. It is, however, deſerving notice, that the number of wardens for the inſpection of ſtuffs at Norwich being too few, they were at this time increaſed from five to eight. A letter on the ſtate of trade, publiſhed in 1667, ſays, clothing-wools were ſo much fallen at that time, that the beſt Spaniſh was ſold at 2*s.* 2*d. per* pound, and Engliſh at 8*d. per* pound. The writer aſcribes the fall in the price of Engliſh wool to our wearing ſo much Spaniſh cloth, a great part not manufactured by ourſelves, as Dutch blacks; but it is obvious, from the price of Spaniſh wool, that the low price of clothing-wools at that time depended on a more general cauſe, affecting all manufacturing countries. To relieve the cloth trade from the great depreſſion under which it laboured between the years 1660 and 1678, various ſchemes were deviſed. Among others, the mayor and common council of London paſſed an act "for the regulation of Blackwell-hall, Leaden-hall, and Welſh-hall, (the three public markets for cloth in London,) and for preventing foreigners buying and ſelling!" By foreigners are underſtood all perſons not free of the city of London. This act, a moſt ſingular monument of the ignorance or ſelfiſhneſs of its authors, prohibits the ſale of all woollen cloths ſent to London, except at the above halls, where certain duties were to be paid upon them, and from whence they could not be removed for three weeks, unleſs they were ſold in the meantime to ſome draper, or other freeman of the city. The hall-keepers were to attend ſtrictly at the halls, and

turn out all foreigners and aliens coming to purchase cloth; and every freeman of the city who should introduce a purchaser into the halls not free of the city should forfeit, for the first offence, five pounds,—for the second, ten,—and for the third, fifteen pounds! Thus, in those days, turning purchasers out of the public markets, and securing the sale to a certain class of buyers, was considered an act for the benefit of the public.

The Irish had, a little before this time, commenced the manufacture of woollens and worsteds, which appears greatly to have alarmed the English manufacturers. The wools of Ireland had increased in quantity, in consequence of a tyrannical act passed a little before this period, to prevent the Irish from sending cattle to England, which obliged them to convert their grounds into sheep-pastures. They were, however, prohibited from exporting their wool to foreigners, it being made felony; and the exportation to England, in any other than a raw state, exposed it to confiscation. About the year 1640 some clothiers from the west of England established a woollen manufacture at Dublin, where it flourished a considerable time. About the same period, sixty families of manufacturers from Holland settled at Limerick: these were ruined by the wars which ensued. Other English clothiers settled at Cork and Kinsale; a few French manufacturers of druggets settled at Waterford; and a more considerable establishment of the cloth manufacture was formed at Clonmel, supported by the capital of some London merchants, who had agents there. These establishments, though obviously inadequate to the supply of one-fourth part of the population of Ireland, excited great jealousy in the English manufacturers; and during the great depression of the woollen trade between the years 1660 and 1668, a part of this distress was ascribed to the rivalry of the Irish clothiers. The English farmers, at the same time, ascribed the low price of wools to the great importations of wools from Ireland; and the merchants ascribed the failure of the foreign demand for cloth to the clandestine exportation of English and Irish wools.

Sir William Petty, in the year 1672, estimates the sheep in Ireland at four millions, and the weight of each fleece at two pounds. The latter, however, is obviously not more than half the true average weight of the fleece, and the number is supposed by some to be below what it was a few years afterwards. If the number of sheep be correct, and taking the fleece of each at four pounds, this would make the total amount of Irish wools only 66,000 packs, of which three-fourths were consumed in Ireland.

The alarm and jealously excited in England by the Irish woollen manufactures produced measures that almost compelled the Irish to export their wools clandestinely to the continent. An act was passed in the year 1699 prohibiting the exportation of woollen manufactures from Ireland, except to a few parts in England and Wales, where the duties imposed amounted to a total prohibition. Various addresses have been presented to the king and both houses of parliament, "beseeching his majesty to take effectual measures to prevent the growth of the woollen manufactures in Ireland." The Irish parliament was influenced to impose a duty in the same year of four shillings in the pound on their own manufactures when exported. These unjust proceedings were intended to annihilate the export trade for Irish woollens; and, in consequence, their wool and worsted yarn that was not consumed at home were sent to England, or to the continent clandestinely. The first four years after the destruction of their manufactures, these exports to England were as follow:

	Stone of Wool, 18lbs. *per* Stone.	Stone of Yarn, 18lbs.	Total of Wool and Yarn.
1700	336,292	26,617	362,909
1701	300,812	23,390	326,202
1702	315,473	43,648	359,121
1703	360,862	36,873	397,735

The average annual amount of wool and yarn, as above, may be stated at thirty thousand packs. But after this period the exports to England declined, owing no doubt to the clandestine exportation of wool to the continent, for which the numerous creeks and harbours offered such facility.

In 1711, and the three following years, the quantity exported to England was as under:

	Wool.	Yarn.	Total.
1711	310,136	52,273	365,409
1712	263,946	60,108	324,054
1713	171,871	68,548	240,409
1714	147,153	58,147	205,800

A few years after this, the decline was still more considerable in the amount of wool exported, but that of yarn continued to increase a little:

1726	51,371	87,261	138,632
1727	58,182	72,047	130,229
1728	49,784	80,428	130,212
1729	38,667	91,854	130,521

A further encouragement to clandestine importation was given by an impolitic duty of 2*s.* 4*d.* *per* stone on wool sent to England, which, as the average price did not exceed 6*s.* 6*d.*, was full thirty *per cent.* on the first cost. It will be seen subsequently, that the woollen manufactures of England were all this time progressively increasing, so that the decline in the imports of wool from Ireland were not occasioned by a declension of trade; the Irish had found other markets for their wool.

From a work entitled "A New Discourse of Trade," by sir Joshua Child, supposed to have been published about the year 1667, we learn several important particulars respecting the woollen trade. "Though our vent for fine cloths and stuffs to Turkey, Italy, Spain, and Portugal, were, he says, declined, yet we retained a considerable part, principally because the wool of which our middling coarse cloths are made is our own, and consequently cheaper to us than the Dutch can steal it from us." In another part he judiciously observes, that the acts for regulating manufactures, resolve themselves at last into a tax on the commodity, without respect to the goodness of it, as most notoriously appears in the business of aulnager, which doubtless our predecessors intended for a scrutiny into the goodness of the cloth; and to that purpose a seal was invented as a signal, that the commodity was made according to the statute; which seal, it is said, may now be bought by thousands, and put upon what the buyers please. Sir Joshua Child admits that wool was eminently the foundation of English riches, and that all possible means should be used to keep it within the realm; but the only efficacious measures to effect it are not penal statutes, but encouragement to trade. The impediments at that time he states to be, 1st, The high rate of interest; 2d, Want of hands, which an act of naturalization would cure; 3d, Compulsion (persecution) in matters of religion. For he adds, "while our neighbours the Dutch have money at lower interest and more hands, by reason of general liberty of conscience, with other free privileges, both to natives and foreigners, there is no question but they will be able to give a better price for our wool than we can afford ourselves, and they that can give the best price for a commodity shall never fail to have it by one means or another, notwithstanding the

oppofition of any laws by fea or land; of fuch, force, fubtilty, and violence, is the general courfe of trade."

The fame enlightened writer appears to have been the firft Englifhman who faw the injuftice, abfurdity, and impolicy of the numerous reftrictions by which the manufacturers were obliged to make cloths of certain weights and lengths, to keep only a certain quantity of looms, or to prohibit dyers, fullers, &c. from carrying on other branches of the trade. "It would be (he juftly obferved) for the advantage of the trade of England, to leave all men at liberty to make what cloth and ftuffs they pleafe, how they will, when and where they will, and of any lengths or fizes."

One of the principal caufes of the decay of our woollen manufactures fir Jofhua Child might not think it prudent to ftate. This was the encouragement given to the confumption of French cloths and woollens in England, together with the total prohibition of Englifh goods imported into France, or the impofition of duties which amounted to a prohibition. The French, under the adminiftration of Colbert, had been extending and improving every branch of the woollen manufacture, and were become our great rivals in foreign markets, as well as at home. In the year 1678, acts were paffed, the 29th and 30th of Charles II., prohibiting the importation of French commodities for three years. From this time trade began gradually to revive, and would have greatly increafed, had not political caufes operated as a check to our profperity.

The improvements introduced in the manufacture of fine cloths by Brewer in 1668, and the more extenfive confumption of Spanifh wool, enabled us to oppofe, with fome fuccefs, the rivalry of the French.

After the acceffion of William, our manufacturers, who were warmly attached to the caufe of religious liberty, being the greater part Proteftant diffenters, were animated to uncommon exertions in the reftoration of their trade. This is evident from the ftate of our exports in the following year after the revolution in 1689, when they amounted to near feven millions, of which the woollens were nearly three millions. This is the largeft amount till the year 1715. A fhort time after the revolution, about the clofe of the century, our writers on Political Arithmetic, Mr. King and Dr. Davenant, give the following eftimate of our national wealth, including wool, &c.:

	£
The annual income of England, of which the people fubfift - - - - - -	43,000,000
Yearly rent of land - - - - - -	10,000,000
Value of wool yearly fhorn - - -	2,000,000
Woollen manufacture of England - -	8,000,000
Woollen manufactures exported - -	2,000,000

From this period, the woollen trade of England kept progreffively increafing, though fubject to fome fluctuations. In the following years the amount exported were as under:

		£
1718	value of woollens exported	2,673,696
1719	- - - - - -	2,730,297
1720	- - - - - -	3,059,049
1721	- - - - - -	2,903,310
1722	- - - - - -	3,384,842

About the year 1722, the plague at Marfeilles, by preventing the exportation of French woollens, increafed the demand for Englifh manufactures confiderably. In the year 1737, the woollen exports amounted to 4,158,643*l.*; and it is remarkable, that at that period the price of wool was uncommonly low.

	£
The yearly medium value of woollen exports, from 1739 to 1748, or to the peace of Aix-la-Chapelle, was - - - - -	3,327,057
Yearly medium of woollen exports, from 1749 to 1753, was - - - - - -	4,189,195

From this time to the period of the American war in 1775, the woollen manufactures, and particularly the worfted, ftill continued to increafe, with occafional checks. The quantity of long combing-wools grown in England had given to the manufacturers of worfted goods a decided advantage over thofe of France, though the ingenuity of the latter in the manufacture of les petites draperies, as the worfted goods are called, was greatly fuperior to what our own workmen had ever fhewn. The demand for worfted goods at home, for tammies and ftuffs, which were the general drefs of females before the year 1775, was very great; befides which, we fupplied with worfted goods many of the fouthern parts of Europe, and particularly Spain and Portugal, for the ufe of their South American colonies, and for the dreffes of the clergy, monks, and nuns, which form no inconfiderable part of the population in thofe countries. About the year 1775, the introduction of Arkwright's inventions for fpinning, carding, &c. into the cotton trade, produced a great change in the article of female drefs in England, ftuffs and tammies being fupplanted by cotton goods, which were become extremely cheap. The failure of the foreign trade alfo greatly affected our manufacturers, both woollens and worfteds. The price of Englifh wool at the latter end of the American war was lower than it had been in any period of our hiftory, when money was of much higher relative value. A tod of 28lbs. of the beft Lincolnfhire wool for combing was not worth more than nine fhillings, and the inferior kinds fix fhillings, or about threepence and four-pence *per* pound. From the time of Elizabeth to the middle of the laft century, fcarcely any alteration or improvements had taken place in the proceffes of manufacture, either in woollen or worfted, beyond the variation of colours or patterns, to fuit the fafhion of the day. The ingenious mechanical inventions of Arkwright, applied to the fpinning and carding of cotton, were foon after modified, and applied to the woollen and worfted trade, and produced an entire revolution in fome of the feats of their manufacture. Before that period, the manufacture of heavy woollens and coarfe worfted goods had been gradually concentrating into Yorkfhire and Lancafhire, where the cheapnefs of living, the active induftry of the inhabitants, and, above all, the cheapnefs and abundance of coal, gave the manufacturers a decided advantage over thofe in the midland and weftern counties. The following table, fhewing the amount of broad and narrow cloths made in the Weft Riding of Yorkfhire, will prove the fact moft decifively. It may be proper to remark, that eighty years fince, about 1738, when our woollen exports exceeded four millions fterling, the total number of pieces of broad and narrow cloth made in Yorkfhire was only fifty-fix thoufand nine hundred. At prefent our woollen exports are only about double what they then were; but the number of cloths manufactured in Yorkfhire is not lefs than four hundred and ninety thoufand pieces, or eight times more than the quantity made at the period above referred to. It muft be remarked alfo, that this account does not include the cloth manufactured in Lancafhire, and the borders of Chefhire adjoining Yorkfhire, nor the blankets, ferges, baizes, flannels, caffimeres, toilinets, carpets, rugs, worfted goods, or any other defcription of woollens or worfteds, except plain and narrow broad-cloths. The total amount of thefe different woollen articles exceed, we believe, in weight, if not in value, that of the woollen cloths.

An Account of the Number of Broad Cloths, milled at the feveral Fulling Mills in the Weft Riding of the County of York, from the 24th of June, 1725, (the Commencement of the Aćt,) to the 12th of March, 1726, and thence annually, diftinguifhing each Year; and of the Narrow Cloths, from the 1ft of Auguft, 1737, (the Commencement of the Aćt) to the 20th of January, 1738, and thence annually, diftinguifhing each Year; likewife the Number of Yards in Length, made each Year, from Eafter Seffions, 1768.

Years.	Broads.		Narrows.		Years.	Broads.		Narrows.	
	Pieces.	Yards.	Pieces.	Yards.		Pieces.	Yards.	Pieces.	Yards.
1726	26671				1772	112370	3223913¾	95539	2377517½
1727	28990				1773	120245	3635612¼	89874½	2306235
1728	25223½				1774	87201	2587364¾	88323	2133583
1729	29643				1775	95878	2841213	96794	2441007
1730	31579½				1776	99733	2975389	99586	2488140½
1731	35563				1777	107750	3153891	95786	2601583
1732	35548½				1778	132506	3795990	101629	2746712
1733	34620				1779	110942	3427150	93143	2659659
1734	31123				1780	94625	2802671	87309	2571324
1735	31744½				1781	102018	3099127	98721	2671397
1736	38899				1782	112470	4458405	96743	2598751
1737	42256				1783	131092	4563376	108641	3292002
1738	42404		14495		1784	138023	4094335	115500	3356648
1739	43086½		58848		1785	157275	4844855	116036	3409278
1740	41441		58620		1786	158792	4934975	123025	3536889
1741	46364		61196		1787	155748	4850832	128740	4058157
1742	44954		62804		1788	139406	4244322	132143	4208303
1743	45178½		63545		1789	154134	4716460	145495	4409573
1744	54627½		63065		1790	172588	5151677	140407	4582122
1745	50453		63423		1791	187569	5815079	154373	4797594
1746	56637		68775		1792	214851	6760728	190468	5531698
1747	62480		68374		1793	190332	6054946	150666	4783722
1748	60765		68080		1794	190988	6067208	130403	4634258
1749	60705½		68889		1795	250993	7759907	155087	5172511
1750	60447½		78115		1796	246770	7830536	151594	5245704
1751	60964		74022		1797	229292	7235038	156709	5503648
1752	60724		72442		1798	224159	7134114	148566	5180313
1753	55358		71618		1799	272755	8806688	180168	6377277
1754	56070½		72394		1800	285851	9263966	169262	6014420
1755	57125		76295		1801	264082	8699242	137231	4833534
1756	33590½		79318		1802	265660	8686046	137016	5023754
1757	55777½		77097		1803	266785	8942798	139575	5023996
1758	60396		66396		1804	298178	9987255	150010	5440179
1759	51877½		65513		1805	300237	10079256	165847	6193317
1760	49362½		69573		1806	290269	9561178	175334	6430101
1761	48944		75468		1807	262024	8422143	161816	5931253
1762	48621		72946		1808	279859	9050970	144624	5309007
1763	48038¼		72096		1809	311239	9826048	151911	5951762
1764	54916		79458		1810	273664	8671042	158252	6180811
1765	54660		77419		1811	269892	8535559	141809	5715534
1766	72575½		78893		1812	316431	9949419	136863	5117209
1767	102428		78819		1813	369890	11702837	142863	5615755
1768	90036		74480		1814	338869	10656491	147474	6045472
1769	92522	2771667¾	87762	2144019	1815	330310	10394466	162355	6649859
1770	93075	2717105	85376	2255625	1816	325449	10135285	120901	5650669
1771	92782	2966224½	89920	2235625	1817	351122	10974473	132607	5233616

In the table that will be afterwards given, it will be feen that the quantity of yards of different woollen articles exported, which are not included with cloths, greatly exceeds that of broad and narrow cloths. Taking this as a ftandard, it would appear that the cloth returned at the fulling-mills in the Weft Riding of Yorkfhire is not more than one-third of the total quantity of woollens and worfteds of every defcription made in the Weft Riding of Yorkfhire, and the borders of Chefhire and Lancafhire. Now to make the quantity of broad and narrow cloth given in the returns of the Weft Riding, would require about one hundred and ten thoufand packs: we may therefore ftate the annual confumption of wool in thefe diftricts to be from two hundred and fifty to three hundred thoufand packs of 240 pounds each; and we may further ftate the amount confumed in thefe diftricts to exceed that of all the other parts of England and Wales collectively by one-third, including hofiery and all other articles made of wool. This will make the total amount of wool manufactured in England to be nearly what we have before eftimated, or five hundred thoufand packs.

The number of perfons immediately employed in the various branches of the woollen manufacture in England was ftated, in the year 1800, to be 1,500,000, and that the trade directly and collaterally employed double the above number. This was afferted in the fpeech of Mr. Law, now lord Ellenborough, in the houfe of lords, as council for the petitioners againft the export of wool to Ireland. But we apprehend that the ftatement greatly exceeds the actual number employed in this trade, including their families.

The amount of the population of the Weft Riding of Yorkfhire is nearly afcertained, and perhaps two-thirds of the whole may be engaged in the woollen manufacture, including the families of the perfons employed. If we ftate thefe to be 340,000, exclufive of the woollen manufacturers in Chefhire and Lancafhire, we fhall certainly not under-rate them. A large part of the Weft Riding being agricultural folely, and in the manufacturing diftricts cutlery, as at Sheffield, and cottons in the more weftern parts, employ no inconfiderable portion of the people. If then we take 340,000 as the amount of perfons, with their families, engaged in the woollen trade in the Weft Riding, exclufive of Lancafhire and Chefhire, and if we fuppofe that they are one-third of the total number of perfons employed in the fame manufacture in England, it will make the whole rather exceed 1,000,000 of manufacturers, including their families, which we apprehend is not far from the true eftimate. We fhall, however, give the precife words of Mr. Law's fpeech in the houfe of lords on the above occafion, the object of which, it muft be recollected, was to enhance the importance of the woollen manufacture. "In order to give your lordfhips fome idea of its magnitude, I may venture to ftate, that there are no lefs than 1,500,000 perfons who are immediately concerned in the operative branches of this vaft manufacture; and if what Dr. Campbell ftates in his 'Political Survey of the Kingdom' be true, that from the wool-grower to the confumer a piece of broad-cloth paffes through 100 different hands, and that there are nearly the fame number of hands dependent on the woollen manufacture, though not actually concerned in it, I may affume that the trade directly and collaterally employs double the above number of hands, or 3,000,000. If we eftimate the magnitude of this queftion (the export of wool) according to the number of perfons interefted in it, it goes to nearly one-third of the entire population of this kingdom, eftimating that population at what is generally reckoned, namely between 9 and 10,000,000." Though the woollen manufactures of England have confiderably increafed within the laft fifty years, we do not apprehend the number of hands employed is greater than before the introduction of mechanical inventions for carding, fpinning, and combing. The working up of one pack of wool, particularly of combing-wool, formerly employed a great number of hands, and was divided into fmall portions, to be fpun in the houfes of cottagers in remote diftricts. This afforded employment to the wives and families of labourers who were engaged in agriculture; but fo much time was occupied in taking out and collecting in the work, that at the period we refer to, few, if any, of the mafter manufacturers in Yorkfhire confumed more than one pack of wool *per* week in their trade. At prefent there are numerous manufacturers in Yorkfhire and Lancafhire, who confume from twenty to fifty packs of wool *per* week.

The cotton manufacture, which may be regarded as of recent date, has employed the population that would otherwife have been thrown out of work in the woollen trade fince the introduction of machinery, and has prevented any inconvenience of this kind from being felt at prefent in Yorkfhire. We may, however, obferve, that many branches of the woollen and worfted trade have been gradually retiring from the fouth of England, and concentrating in the Weft Riding of Yorkfhire and in Lancafhire. Thefe diftricts were the firft to introduce mechanical improvements into the woollen manufacture, and thus gained a decided advantage over the more ancient feats of the woollen trade. For feveral years afterwards the effects were felt in the manufacturing diftricts in the weft of England, and great diftrefs from want of due employment for the labouring claffes was the confequence.

At prefent all kinds of machinery that have hitherto been applied to wool are extenfively employed in the weft of England, and the manufacture of fuperfine cloth is in a flourifhing ftate in the counties of Gloucefterfhire, Somerfetfhire, and Wiltfhire, all ancient feats of the clothing trade. The manufacture of broad-cloth in other parts of the fouth and weft of England is not carried on to any great extent. The manufacture of flannels, ferges, baizes, &c. though branches of the woollen manufacture, are diftinct from the cloth trade, and feldom carried on in the fame diftrict.

The export of woollen goods of all kinds from England, in the year 1815, amounted in declared value to ten millions one hundred and ninety-eight thoufand pounds. This was rather an extraordinary quantity; and in the following year the exports fell under nine millions, which may be taken as the regular annual amount of woollen exports at prefent.

The following table gives the amount of different kinds of woollens exported, with their value, and the places to which they were fent in the year 1816; a year in which our foreign trade was confidered as in a declining ftate. It may be worthy of remark, that though our woollen exports fcarcely reached eight millions and a half, the amount taken by the United States of America in that year exceeded three millions; a fact which proves the vaft importance of the American market to our manufacturers.

An Account of the Quantity of Woollen Goods exported from Great Britain, in the year ending the 5th
possible, the various Articles,

Countries to which exported.	Quantity and declared Value of Woollen									
	Cloths of superfine, second, and inferior Quality.		Napped Coatings, Duffles, &c.		Cassimeres.		Baizes of all Sorts.		Flannel.	
	Quantity.	Declared Value.	Quantity.	Declared Value.	Quantity.	Declared Value.	Quantity.	Declared Value.	Quantity.	Declared Value.
	Pieces.	L.	Pieces.	L.	Pieces.	L.	Pieces.	L.	Yards.	L.
Russia - - - - - -	79671	777074	27	153	2180	19857	128	565	62436½	5633
Sweden - - - - - -	56½	979	—	—	1	4	—	—	832	54
Norway - - - - - -	588	4921	217	949	60	378	27½	165	4335	389
Denmark - - - - -	717	7447	34	130	354	2308	—	—	8142½	646
Poland - - - - - -	2	45	—	—	—	—	—	—	100	10
Prussia - - - - - -	83	1100	67	324	214	1544	3	18	1324	137
Germany - - - - -	9274	54042	27740	110457	27882	103534	200	580	144972	9494
Holland - - - - - -	9892	53294	13374	63462	2374	9367	1741	11950	37928	3373
Flanders - - - - -	3164	23086	6586	29540	1575	7364	13	94	44555	4602
France - - - - - -	73	721	—	—	67	910	¼	3	1944	154
Portugal, &c. - - - - -	39854	292141	7466	38755	3931	30037	13114	80377	14859	1355
Spain, &c. - - - - -	3395½	30286	1228	5071	930	5975	5584	38139	42554	4411
Gibraltar - - - - -	4344	32520	1270	6805	950	5415	883	4886	79720	8913
Italy - - - - - -	7729	45360	2772	11765	658	3395	48	285	20623	1535
Malta - - - - - -	8453	45964	1305	5466	811	4274	53	198	4730	537
Turkey and Levant - -	185	2850	51	258	—	—	—	—	1450	160
Ireland and Isle of Man - -	21734	327049	61	399	4008	60851	91	556	200707	18898
Isles, Guernsey, Jersey, & Alderney	991	13975	93	515	20¼	194	140½	540	25054	2213
Asia - - - - - -	19433	407614	170	936	231	2777	330	1374	225487	28130
Africa - - - - - -	1485½	17396	498	2538	1122	6586	241	1460	14386½	1209
America; *viz.* United States -	195124	1463028	19798	73143	39899	263284	4446	12787	2288758	187940
——— British Northern Colonies	32412	246504	1827	5544	2248½	15442	1051	4227	484129	35971
——— West Indies - -	16649¼	114544	529½	1926	2708	16991	8109	40098	69729	6451
——— Foreign Continental Colon.	33319	238796	5409	30863	2911	18888	13926	80236	12999	895
——— Honduras - - -	30	337	—	—	50	312	—	—	700	53
Total - -	488658¾	4201073	90522½	388999	95184¾	579687	50129¼	278538	3792454½	323163

of January, 1817, diftinguifhing the Countries to which exported, and alfo diftinguifhing, as far as and their refpective Value.

Goods and Yarn exported from Great Britain.

Blankets and Blanketing.		Carpets and Carpeting.		Stuffs, Woollen or Worfted.		Stockings, Worfted.			Sundry Articles confifting of Hofiery not defcribed, Rugs, Coverlids, Tapes, &c.	Woollens, mixed with Cotton.		Woollen and Worfted Yarn.		Total declared Value of the preceding.
Quantity.	Declared Value.	Quantity.	Declared Value.	Quantity.	Declared Value.	Quantity.		Declared Value.	Declared Value.	Quantity.	Declared Value.	Quantity.	Declared Value.	
Yards.	L.	Yards.	L.	Pieces.	L.	Doz.	Prs.	L.	L.	Yards.	L.	Lbs.	L.	L.
6742	885	30863	6335	2261	4723	208	0	276	1234	12433	2188	—	—	818923
58	7	1240	421	15	25	4	9	9	21	—	—	—	—	1520
268	37	645	155	479	1096	41	4	62	319	1715½	426	—	—	8897
382	51	1047	297	891	1850	10	0	13	152	786	270	—	—	13164
180	20	1130	265	52	120	—		—	—	—	—	—	—	460
—	—	1832	485	188	382	3	0	3	1028	2260	652	—	—	5673
12660	1285	73579	17742	37748	80244	3936	9	5201	15052	135862	26041	—	—	423672
7690	600	28737½	5462	31447	62391	8636	10	10384	3986	19730½	3968	—	—	228237
6663	685	6162	754	5635	13326	5145	6	6499	3645	31785	9072	—	—	98667
15	4	352	88	345	1112	196	0	240	443	2338	686	—	—	4361
44745	5026	18043	3394	27472	72091	3417	0	4153	35206	25190	5919	—	—	568454
10152	1189	6064	1086	11644	29281	2840	0	3666	25931	5846	1505	—	—	146540
2150	219	2600	474	10659	24874	892	10	1029	13846	19593	4563	—	—	103544
570	68	2765	627	14852	37930	62	0	84	1060	2894	720	—	—	102829
100	15	317	83	3682	9603	87	0	113	693	3382	389	—	—	67335
650	70	13595	3366	1816	4222	20	0	42	104	—	—	—	—	11072
30500	4727	46894	12042	8150	20883	12453	0	14156	11582	121483	25444	523638	65613	562200
4280	638	7211	1555	837½	2319	650	6	916	280	548½	150	—	—	23295
23824	3956	9879	2312	187820	572325	629	0	1039	8863	4044	895	—	—	1030221
14190	1237	3718	645	1638¼	3353	1520	0	1477	1139	2940	813	—	—	37853
1265746	165729	526964	109529	202061	609628	69059	6	75513	47802	198268	21284	—	—	3029667
258359	32455	69563	14293	21362	55511	18709	4	22190	8995	24103	4410	8757	2086	447626
233597	22153	3080	768	13094	27649	837	6	1133	4916	215912	14973	—	—	251602
39320	3750	9946	2008	9810	21845	2483	0	2851	7746	54805	9928	—	—	417806
1860	120	—	—	14	28	7	0	11	—	—	—	—	—	861
1964701	244926	866226½	184186	593972¾	1656811	131849	10	151060	194043	885918½	134296	532395	67699	8404481

If we ſtate the amount of woollen goods exported to be about one-third of our own conſumption, or from one-third to one-fourth, which is probably more correct, this would make the total value of manufactured woollens to exceed thirty millions annually. Of the woollen goods exported, the quantity conſumed on the European continent ſcarcely exceeds three millions ſterling in value, and a great part of that amount given in the preceding account was for army cloth. Hence it appears, that a very ſmall proportion of the general population of Europe is indebted to this country for its woollens, including under the term both woollen and worſted goods. The increaſed demand for woollens of every deſcription in England ariſes partly from the increaſe of population, but more from the increaſing demand for articles of luxury or convenience. In the middle of the laſt century, carpets were ſcarcely to be ſeen in the country, except in the houſes of the nobility; at preſent almoſt every houſe in England, except thoſe of cottagers and the labouring claſſes, has carpets ſpread in ſome of the rooms. The conſumption of worſted yarn in articles of furniture, and in the linings of carriages, and what is called horſe millinery, is very great; add to which the people of England are better dreſſed than they were formerly. We may from all theſe cauſes ſtate, that the home conſumption of woollens, in proportion to our population, is double that of any other nation in Europe. To prove that we do not over-rate the proportion of woollens conſumed at home, it may be ſufficient to ſtate, that the Weſt Riding of Yorkſhire alone manufactured, in the year 1817, nearly twice as many pieces of cloth as were exported in that year; but few woollen broad-cloths are made for exportation in the weſt of England, the manufactures there being principally fine and ſuperfine cloth for home conſumption, the value of which *per* yard on the average is much greater than that of the Yorkſhire cloth. In the preſent ſtate of Europe, we think it an encouraging circumſtance to our woollen manufacturers, that ſo large a proportion of their goods are conſumed at home, where the demand will remain certain; and again, that the United States of America take ſo conſiderable a part of our exports, as from the increaſing population of theſe ſtates, we may expect that the demand will be increaſing for many centuries, and will ſoon exceed what it will be in the power of this country to ſupply.

In the year 1800, the woollen manufacturers of England were greatly alarmed at the liberty which was intended to be granted, of exporting wool to Ireland, and petitioned parliament againſt the meaſure. The grounds on which their alarms reſted, were partly the preference given to the Iriſh, and partly the ſuppoſed facility that would be afforded to ſmuggling wool to the continent. Several manufacturers and wool-dealers from different parts of the kingdom were examined before the two houſes of parliament; but neither in their evidence, nor in the ſpeeches of the learned council, who were heard in ſupport of the petitioners, can we trace any comprehenſive or enlightened views of the ſubject. The objections urged againſt the export of wool were grounded principally on the practice of former reigns, particularly thoſe of Edward III. and queen Elizabeth: but the facts we conceive were in oppoſition to the ſtatements; for during the whole of the latter reign, in which our woollen manufactures were in a highly flouriſhing condition, the export of wool was freely admitted, on the payment of certain duties; and during the reign of Edward III., the prohibition to export wool under heavy penalties was confined to denizens and foreigners, in order to ſecure a larger amount of duties to the king, the former paying leſs duty on exports than natives; nor was it till the reign of Charles II. that the export of wool was ſtrictly prohibited. All the former prohibitions were evadable by licences, which were readily granted for money. It is from this reign, therefore, we muſt date the prohibition to export wool, as forming an eſtabliſhed law of the land; and it is not unworthy of remark, that immediately after this period, and to the time of the revolution in 1688, our woollen manufactures were in a very declining ſtate, which proves that they had not derived much benefit from the meaſure. The policy of admitting the export of wool has been again recently agitated in parliament, and has renewed the alarm of the manufacturers. It is not by precedents drawn from former ages, but ſolely by the wiſdom and juſtice of the meaſure, as applicable to one preſent condition, that a queſtion of this kind ſhould be determined. With reſpect to ſhort or clothing wool, we believe that a permiſſion to export it would not produce the leaſt effect, as we already import theſe wools from almoſt every nation in Europe; it is not, therefore, probable, that foreigners would give a better price for them than our own manufacturers can afford. With long combing-wools, the caſe is ſomewhat different, as by the acknowledgment of the French themſelves, theſe wools are wanted to mix with and improve their own. We apprehend, however, that as much is exported at preſent clandeſtinely in the form of worſted yarn, as the market may require, the free export of cotton yarn giving great facility for evading the penalty, by packing them together. The permiſſion to export wool to Ireland, which was granted in 1800, has not been attended with any one of the fatal effects which our manufacturers anticipated; nor do we apprehend, that permitting the free export of wool under certain duties would be found to injure our own woollen trade.

In taking this view of the ſubject, which we truſt is an impartial one, we readily admit that the permiſſion to export wool, were it granted, would not be attended with any permanent benefit to the landed intereſt. A ſmall pamphlet on the ſubject, recently publiſhed by John Maitland, eſq., contains the following judicious obſervations:—"The manufacturer of our native wool claims from government the preſervation of it for his uſe; for *by the ſtatute law of the land, he is confined to its ſoil for the expreſs purpoſe of working up the wool which grows upon it.* This wool cannot, therefore, upon any juſt or moral principle, be permitted to go out of the country in an unmanufactured ſtate, without allowing the manufacturer to follow it, or without obliging the grower and exporter of it to maintain him and his children." This is ſo obviouſly juſt, that whenever the export of wool is admitted, we cannot any longer, as at preſent, prohibit the woollen manufacturers from emigrating and carrying their induſtry to the beſt market. "The wool," as Mr. Maitland elſewhere obſerves, "does not on an average compoſe more than one-ſixth part of the value of the animal on which it grows; and the manufacturer, by obtaining this ſixth part, at ſuch a moderate rate as may enable him to ſell his goods, when manufactured at a reaſonable profit, inſures to the owner of land a moral certainty of obtaining the full value for the remaining five-ſixths, and receiving an ample price alſo for all the other productions of his ground." The truth of this obſervation we know to be fully proved in the Yorkſhire markets. Whenever there is any conſiderable depreſſion of the woollen trade, it is always attended with a decreaſed conſumption of animal food, ſupplied principally from Lincolnſhire, and the counties which produce the largeſt quantity of wool. Should the permiſſion to export wool be attended with any effect in diminiſhing our own manufactures, the reſult would be highly injurious to the land-owner, who would then have to find new cuſtomers for

his general produce, and new aſſociates to ſhare with him the burden of taxation.

The prices of heavy combing-wool in Lincolnſhire, Nottinghamſhire, or Leiceſterſhire, may be taken as the average price of this kind of wool over the whole kingdom, there being little variation in the value of this wool from different diſtricts. The following table will ſhew what have been the prices for a great part of the laſt century:

Price *per* Tod of Lincolnſhire Fleeces, the Tod weighing 28 lbs.

	£	s.	d.
1706	0	17	6
1707	0	16	6
1711	0	13	0
1713	0	17	0
1714	0	18	0
1715	0	18	0
1716	0	19	0
1717	1	3	0
1718	1	2	3
1719	1	2	0
1720	1	0	0
1721	1	0	0
1722	1	0	0
1723	0	17	6
1724	0	16	0
1725	0	16	0
1726	0	15	9
1727	0	16	0
1728	0	18	0
1729	0	18	0
1730	0	18	0
1731	0	19	0
1732	0	19	0
1733	0	18	6
1734	0	16	0
1735	0	14	0
1736	0	14	0
1737	0	14	0
1738	0	13	6
1739	0	13	0
1740	0	14	0
1741	0	14	0
1742	0	15	0
1743	0	19	6
1744	1	1	0

From the year 1744 to the year 1777, the prices, though occaſionally fluctuating, continued much the ſame as in the preceding years, but we have not the means of aſcertaining preciſely what they were in each year. The following table will ſhew the prices of Nottinghamſhire and Leiceſterſhire heavy combing-wool, taken from the moſt authentic ſource. We conſider the value of this wool to have been fully equal to that of Lincolnſhire on each year.

Price *per* Tod of 28 lbs. of Nottinghamſhire and Leiceſterſhire heavy Combing-Wools.

	£	s.	d.
1777	0	18	0
1778	0	15	0
1779	0	11	0
1780	0	11	6
1781	0	10	6
1782	0	9	0
1783	0	12	0
1784	0	16	0
1785	0	12	0
1786	0	13	0
1787	0	17	6
1788	0	17	0
1789	0	18	0
1790	0	18	0
1791	0	19	6
1792	1	2	6
1793	0	18	0
1794	0	17	6
1795	0	19	0
1796	1	1	0
1797	1	0	6
1798	0	18	0
1799	1	1	6
1800	1	4	6
1801	1	10	0
1802	1	10	0
1803	1	9	0
1804	1	12	0
1805	1	13	6
1806	1	12	0
1807	1	4	6
1808	1	4	6
1809	1	8	0
1810	1	10	0
1811	1	5	0
1812	1	10	0
1813	1	14	0
By the end of the year	2	5	0
1814 - - 2 2 0 to	2	12	0
Spring of 1815	2	16	0
1815	2	10	0
1816	1	10	0
1817 - - 1 14 0 to	2	0	0

The above were the average prices of the beſt lots; the inferior ones might range from one to two ſhillings *per* tod under the prices here given. It may be obſerved, that the price of this kind of wool was lower towards the cloſe of the American war, or about the year 1781 and 1782, than in any former or ſubſequent period of our hiſtory, if we take into conſideration the relative value of money. At that time, the quantity of wool unſold in the hands of the farmer was nearly equal to three years annual growth; a quantity too large to have been conſumed by our manufacturers, had not the introduction of machinery enabled them to work it up with much greater facility than formerly. The average weight of theſe fleeces may be ſtated at four or ſeven pounds each fleece to the tod of 28 pounds. Since the commencement of the preſent century, the price of this kind of wool, it will be ſeen from the above table, has been amply ſufficient to remunerate the wool-growers; and we confeſs we are utterly at a loſs to diſcover on what grounds of ſound policy or intereſt they would wiſh to make any change in the laws reſpecting the export of wool. With reſpect to ſhort or clothing wools, any change in the exiſting laws would make no alteration whatever in the price; for it is the extreme of prejudice to aſſert, that our native clothing fleeces are neceſſary to the foreign manufacturer, either to ſupply his demand or improve the quality of his own wool. We might with equal juſtneſs revive the abſurd opinion, ſo confidently maintained a few years ſince, that the beſt Spaniſh wool would not make cloth without an admixture with that of England.

Woollen *Manufacture, Process of.* In an early part of this work, under the article Cloth, we have given a general view of the process of cloth-making, furnished by a principal manufacturer in the west of England. In the present article, we shall confine our account chiefly to those improvements in the processes which have since been introduced, and shall add a description of the machines which were only slightly noticed in the article Cloth, and give references to the plates. The processes of the woollen manufacture may be classed under two heads; those by which wool is prepared for the weaver, and those by which the cloth is finished after it is taken out of the loom. The sorting of wool has already been referred to under the article Wool. English wool is supposed to be sufficiently cleaned from pitch marks or other extraneous substances by the wool-sorter, and left by him in a proper state to commence the process of cloth-making. Spanish wool in the bale has generally some part of the pitch employed to mark the sheep still adhering to it, which must be carefully cut off. It was till recently the practice to beat the wool with rods, in order to shake out the dust and open the staples; but this is now principally done by an opening machine with long coarse teeth, called a devil, or wool-mill. Spanish wool is frequently so hardly pressed together in the bag, that it requires to be opened out by beating, to prepare it for the further processes.

In the west of England, wool is generally scoured before it is dyed or carded; but in Yorkshire this is seldom practised on wool intended for white cloths, and among the smaller manufacturers who dye their own wool, it is frequently put into the dyeing-vat unscoured; a practice which injures the brightness of the colours, but which enables the manufacturer to make a greater weight of cloth with the same quantity of wool. There is also some saving of labour and expence; but this is more than counter-balanced by the increased quantity of oil *per* pack required for unscoured wool, which is at least one-third more than would be necessary if the wool were scoured. In the west of England, where the wool is scoured previously to its manufacture, the process is carried on with a degree of neatness and cleanliness, which form a perfect contrast with the horrid stench and disgusting filthiness of the woollen factories in Yorkshire. For fine cloths, olive-oil, called Gallipoli, from the part where it was supposed to be sent, is principally used; and for the coarser cloths rape-oil. Where attention to colour is not required in very coarse goods, fish-oil is sometimes employed; but if the latter remain in the wool or cloth, it turns it brown, undergoing a degree of fermentation injurious to the cloth, and which sometimes occasions spontaneous combustion. To lessen the expence of oil for coarse cloths, some manufacturers in Yorkshire make use of a mixture of soap and water with oil, which answers very well in moist weather, if the wool be immediately carded and spun; but if it remain some time unwashed, or the weather be very hot, the mixture evaporates. It has been attempted to work wool without any oil whatever, but without success. The use of oil is to cover the surface of the fibres, and enable them to slide easily over each other in carding or spinning. What we have before said of the structure of the surface of wool or hair, under the article Wool, will suffice to shew the advantage that must result from oiling. The wool is sprinkled with oil as evenly as possible. In Yorkshire the proportion on fine wool is about six gallons *per* pack, and this is more equally distributed over it by the wool-mill, through which it passes previous to the process called scribbling. This process is a kind of coarse carding, and is performed on a machine similar to that used for scribbling cotton, but larger, and with coarser cards, the principle being similar to that of the carding-machine, hereafter to be described. By this engine the longer fibres are broken down, and they are all laid straight and nearly parallel to each other. The wool leaves the roller of the scribbling-mill in one thin undivided sheet, and the more clear, even, and transparent it appears when held between the eye and the light, the more perfectly has the operation been performed. On the carding-engine, the operation is repeated on finer cards; but instead of leaving the machine in one continued sheet, it is finally divided into separate portions, which by a fluted roller are formed into separate round pieces about one inch in diameter, and two feet three inches in length. The fibres are now arranged so as more easily to slide over and twist round each other in the next process, which is a kind of coarse spinning called slubbing, performed with the slubbing-machine, which will be described. On this machine each of the rolls from the carding-machine are joined together, and drawn out into a loosely-twisted thread, and wound round a spindle, forming what is technically called a *slubbing*. These slubbings being taken to the spinning jenny, which will also be described, are twisted in an opposite direction, and drawn out into threads of yarn of the requisite length. For very fine yarn used in shawls, a machine called the mule is sometimes employed, nearly similar to the cotton mule (see *Manufacture of* Cotton), the slubbing passing through rollers which assist in drawing out the thread smaller and more regular. The yarn is now prepared for winding, sizing, warping, and weaving. (See Cloth.) Since the article Cloth was written, broad-cloth is almost universally woven by one person only in a loom, making use of the fly-shuttle. (See Weaving.) The next process is scouring and burling, already described under the articles Cloth and Fulling. The cloth is then sent to the fulling-mill; the finer kinds are prepared for fulling by a mixture of soap and water; in coarse kinds, fuller's-earth supplies the place of soap. (See Fulling-*Mill*, and a farther description at the end of the article.) The principle on which the felting depends has been described under the article Wool. By the process of fulling, the cloth becomes shortened in length and breadth, and the fibres are incorporated and intimately united with each other. In the best manufactured cloths, this incorporation is so complete, that the separate threads can scarcely be distinguished, the bottom of the cloth appearing to form one even continuous substance. An improvement in this respect has recently been made at Leeds, by spinning the wool much softer and thicker than has usually been the practice, and uniting the threads in the fulling-mill, and then working the substance of the cloth down to a requisite degree of thinness by the gig-mill, hereafter to be described. At the end of the process, the face or surface of the cloth is much softer, and greatly superior in appearance to cloth manufactured in the common process. A pack of wool of 240 lbs. will make when milled about one hundred and twenty yards of mixed or coloured cloth from fifty to sixty inches in breadth, according to the quality and fineness of the wool. The process of raising, shearing, and pressing, have been mentioned under the article Cloth, and will be more fully described when an account is given of the gig-mill and shearing-machine. The object of these processes is to cover the thread with a soft pile, consisting of the fibres of the wool, cut down to an even surface over the whole piece.

There are various kinds of woollen goods worked on the same principle as cloth, and made with both the warp and the

weft of carded wool, but which being unmilled, or finifhed in a different manner, receive different names. Blankets are manufactured on the card, but from wool that poffeffes a greater length of ftaple, and which therefore admits of a deeper pile, being raifed on the furface. The yarn is fpun thicker, and left as foft as poffible, in order that it may form a full cover or pile. Fine blankets are made much ftouter and heavier than coarfe ones; they are both fcoured in the mill, but are fcarcely fuffered to undergo the fulling procefs. Thick cloths with a long pile, called duffields, fearnoughts, and bear-fkins, are manufactured on the fame principle as blankets, but they are milled much thicker and dyed, and alfo raifed to a deeper pile. Flannels and very light cloths, fuch as Bath coatings, are ufually fpun fmall, in proportion to the quality of the wool. In weaving plain cloths, the chain or warp is equally divided by the gears, one half of the threads being above and the other half below, and they crofs each other every time the thread of the weft is thrown through by the fhuttle. In weaving kerfeymeres or caffimeres, on the contrary, the warp is unequally divided, to produce what is called the twill, or tweel, (fee WEAVING,) one-third being always above and two-thirds below the fhuttle as it paffes. It is owing to this arrangement of the warp, that it forms a flanting or diagonal rib acrofs the body of the cloth, which is the diftinguifhing character of this kind of woollens. See DRAUGHT *of Looms*.

Caffimeres are ufually fet in the loom from thirty-four to thirty-fix inches wide, and milled to twenty-feven inches. Forty pounds of wool from the bag will make rather more than fixty yards of common milled fine caffimeres; the double milled ones make lefs in proportion to the degree of milling they receive.

Swandowns and toilinets are made with a cotton warp; the weft is woollen or worfted yarn of various colours, according to the patterns required. Woollen cords have alfo the warp of cotton and the weft of woollen; they are woven and cut precifely in the fame manner as cotton cords. See FUSTIAN.

Serges are made with the warp of worfted and the weft of coarfe woollen yarn, and are twilled. Thefe goods have been for a very long time manufactured extenfively in Devonfhire, and are principally purchafed by the Eaft India company for the China trade.

Carpets have worfted warps and woollen wefts. See CARPET and WEAVING.

From the moft remote period of the woollen manufacture until the latter end of the laft century, or about the year 1780, very few, if any, mechanical improvements had been introduced into it. During the whole time the various proceffes were carried on nearly in the fame manner, but with greater or lefs fkill, and were employed upon materials more or lefs valuable. The carding and fpinning of wool, and the weaving and finifhing of cloth, in the early part of the reign of George III., were effected by the fame machines as in the time of Edward III., which probably were fimilar to thofe of the ancient Romans, but more rude in their conftruction. In an art which had feen fo many centuries roll on without any change, it did not appear poffible to the manufacturer that any improvement could be effected; and had not the genius of Hargreaves and Arkwright changed entirely the modes of carding and fpinning cotton, the woollen manufacture would probably have remained at this day what it was in the earlieft ages of civilized fociety. That it would have been better for general fociety if it had fo remained we readily admit; but after the improved modes of working cotton were difcovered, this was impoffible. The fpinning jenny, which was the fame as that employed in the cotton manufacture, but fomewhat larger, was introduced into Yorkfhire from Lancafhire about the year 1780, but did not become general till about three years afterwards. In the firft jennies, not more than eighteen or twenty threads could be fpun, and the mode of winding the thread upon the fpindle was very imperfect. The carding was ftill effected by the hand, and the flubbing or roving was prepared on the common fpinning-wheel. For fome time confiderable difficulty was experienced in carding by machinery, particularly in clearing the wool from the card; and a flight change in the conftruction of the machine was found neceffary to prepare the wool for the flubbing-billy, of which an account will be given in the defcription of the carding-machine. Soon after this, the carding and fpinning of wool and yarn by machinery became general through the manufacturing diftricts of the Weft Riding of Yorkfhire, and large mills were erected, in which the carding and fcribbling machines were turned by a water-wheel, and the roving or flubbing performed on the billy. The wool carded at thefe mills was fent to the fmaller manufacturers in the ftate of flubbing, and the farther procefs of fpinning was effected on jennies in their own premifes. Before the year 1787, the old proceffes of carding by the hand, and fpinning on the wheel, were entirely difcontinued in Yorkfhire; but it was fome years after before the new proceffes were generally introduced in the weft of England, and thus, as we have before ftated, the woollen trade became more concentrated in Yorkfhire, where cloths could be manufactured at lefs expence. About this time, machinery began to be applied to the combing and fpinning of long combing-wool, to make worfted yarn. See WORSTED *Spinning*.

In confequence of the great increafe of trade in Yorkfhire, it was found difficult to obtain fituations for mills to be turned by water, and the application of the fteam-engine to woollen machinery became very general. The abundance of fuel was highly advantageous to the Yorkfhire manufacturer; and it was found to be equally cheap to work the machines by fteam as by water, where any confiderable rent was paid for the water. The motion of the improved fteam-engine was alfo rendered as regular as a water-wheel, and the great inconvenience and lofs from the interruption of the works by frofts or continued droughts were thereby avoided.

The fmaller manufacturers in Yorkfhire were at firft benefited by the introduction of machinery, but in a little time large capitalifts began to engage in the woollen trade, and performing all the proceffes with their own machinery, they were enabled to work cheaper and underfell the fmaller makers. The facility alfo with which wool could now be worked up kept the markets always well ftocked with goods, and prevented the manufacturers from taking the advantage of a temporary fcarcity or a brifk demand, which they had formerly done, an overftocked market always reducing the profits.

Soon after the year 1800, the number of fmall manufacturers began rapidly to decreafe many of them, being ruined by the change which had taken place, and compelled to become workmen in the factories of the large capitalifts.

The gig-mill and the fhearing-machine were not introduced into Yorkfhire until they had been feveral years employed in the weft of England, owing to the refiftance made to them by the working cloth-dreffers or croppers in the north.

The manufacture of worfted is properly a branch of the woollen manufacture, and noticed as fuch in our hiftory of its progrefs in England; yet the mode of manufacture, both in preparing the worfted yarn and finifhing the goods, being

entirely different from woollens made of carded wool, and part of it being applied to hosiery, we refer, for a further account of it, to the articles WORSTED *Manufacture*, and WORSTED *Spinning*.

Description of the Machines employed in the Woollen Manufacture.—The *wool-mill*, or *willy*, is the first machine which is employed on the raw wool to open and disentangle the close matting, in which the wool comes from the wool-stapler. It is also used for clearing the dyed wool from the dye stuff, and again for mixing different parcels of wool together; also for incorporating the oil with the wool.

The wool-mill used in Yorkshire consists of a cylindrical drum, about three feet long and two feet and a half diameter, which is made to revolve near three hundred times *per* minute. Its circumference is furnished with teeth or spikes, and immediately above it five small rollers are placed, which are also furnished with similar teeth. The teeth of the rollers and those of the drum intersect each other when they all turn round; and the teeth of the five small rollers also intersect each other. The cylinder and rollers are inclosed in a box or case, which is closed on all sides, except a door in front, which turns down, the hinges being at the lower side. When this door is shut up it stands in a perpendicular plane, very near to the teeth of the drum; when the door is opened, or turned down into the horizontal position, the wool is laid upon it, about one pound weight at once, and the door being closed the wool is brought within reach of the teeth of the cylinder, which take the wool and carry it upwards, so as to work it between the teeth of the cylinder and those of the five rollers placed over it. This effects the opening of the wool, and breaks the fibres if the staple is too long: it also separates the matted fibres. In about three seconds, the pound of wool is generally sufficiently worked, during which time the cylinder has made about fifteen turns. The lower part of the case in which the cylinder revolves is a grating of wooden rods, through which the dirt and dust escape. The cylinder is fitted very close to this grating, so that the wool cannot escape from the cylinder, but is carried round in it, and is thus repeatedly submitted to the action between the teeth of the cylinder and those of the rollers. When it is judged that the wool is sufficiently worked, the door is opened again, and the centrifugal force throws out the wool in an instant; a fresh charge is then laid upon the door, and shut up in the machine. A preferable mode is to have two doors on opposite sides of the case; one to put in the raw wool, and the other for the finished wool to come out at.

The wool for coarse goods is passed several times through the wool-mill; first, to break the mats of the raw wool and render it light; then a second time after it is dyed; a third time to mix the different sorts together; and lastly, after the wool is oiled, it is passed a fourth time through the wool-mill, with a view to incorporate the oil well with the fibres of the wool.

Scribbling-Machine.—This is the first stage of carding. The operation tends to disentangle the fibres which were before closely entangled, and draw them out separately, so as to render the wool light and flaky. The scribbling-machine is very similar to the carding-machine, having a large cylinder or drum, which is covered on the surface with sheets of leather stuck full of projecting wire-teeth, called card-wires. The teeth are so close together as to cover the whole surface of the cylinder, like the bristles of a brush. This cylinder is turned rapidly round by the machinery, and the wool is regularly and slowly supplied by feeding machinery to its teeth, which take it up, and the cylinder, as it were, clothes itself with wool. This wool is carded or worked by the teeth of several other smaller cylinders, called workers and clearers, which are fixed around the great cylinder in pairs. The teeth of the workers take the wool from the great cylinder, and give it to the clearers, which return it again to the great cylinder. It is then transferred to another worker, and by its clearer is given back to the great cylinder, and so on. It is by the repeated transferring of the wool from one cylinder to another, that the chief action of scribbling or carding is performed. The teeth of the different cylinders do not actually touch each other, but they work so near together, that the fibres of the wool which the teeth of one card contains are caught by the teeth of the other card, and drawn out a very few at a time. This action tends to separate the fibres, and renders the wool light and open, and also distributes the wool with great evenness over the surfaces of the cylinders. After the wool has passed between three or four pairs of workers and clearers, it is taken up by a cylinder, called the doffer, which is smaller than the great cylinder, and turns round very slowly. The wool is stripped off from this doffer by a steel comb, which is situated parallel to the axis of the doffer, and is moved rapidly up and down by a crank through a small space. In ascending, the comb does not touch the doffer; but when the comb makes its down stroke, it comes in contact with the teeth of the cards, and combs out almost all the wool they contain. As the doffer turns round very slowly, and the comb acts at small intervals, the successive portions of wool which it combs or strips off, hang together in a continued fleece or web of a very thin texture, which hangs down from the doffer, and is received in a basket.

The wool in this state is said to be scribbled, but the fibres are not yet sufficiently combed out or separated; for on examination of the scribbled wool, many small knots and films of wool are found, which are still closely entangled. The scribbling is therefore repeated twice or three times, and then the wool undergoes another operation, which is called carding, but which is very nearly the same as the scribbling, only the wool is formed into small cylindrical rolls, which are the first rudiments of a thread.

We have thought it needless to give a drawing of a scribbling-machine, as it may be readily conceived from the following description of the carding machine.

Carding-Machine. (See *Plate* IV. *Woollen Manufacture.*)—A is the wood frame of the machine, but the best machines have cast-iron frames; C C is the outside of the large cylinder, which is about thirty inches diameter, and twenty-six inches wide: its axis is supported on bearings at each side of the frame, and it is put in motion by an endless strap applied upon a pulley at one end of its axis, which pulley cannot be seen in the figure. The cylinder revolves about 100 times *per* minute. B is an arch of wood to receive screws, which support the six small cylinders marked 2 *a* and 2; these are the workers and clearers. The workers 2 *a* are larger, and turn slower than the clearers 2; each worker is acted upon by its clearer, and both worker and clearer act against the cards of the great cylinder.

The raw wool is spread evenly upon the feeding-cloth 5, at one end of the machine: it is an endless sheet stretched over two rollers, one of which has a cog-wheel G upon the end of its axis, and receives motion from a pinion situated behind the pulley F. This pulley is turned by an endless cord passing round a pulley *n*, fixed upon the cog-wheel E, which is turned by a pinion 8 on the end of the axis of the great cylinder. The wool which is spread on the cloth 5 is taken off, between a pair of feeding-rollers, which are clothed with cards laid on in spiral fillets. These rollers cannot be seen, being within the frame; they are about 2½

inches diameter, and are turned round by toothed pinions on the axis of the cloth-roller, ſo as to move rather quicker than the feeding-cloth. The feeding-rollers give the wool to a cylinder 4 *a*, called the carrier, which is about nine inches diameter. The carrier works againſt the cylinder C; but as its ſurface moves more ſlowly than the ſurface of the cylinder, the wool contained in the teeth of the carrier is taken up by the cylinder. The carding-machine repreſented in our plate is ſhewn with a cylinder 3, beneath the carrier; this is not uſed in the preſent machines, but the feeding-rollers give the wool at once to the carrier 4 *a*.

That part of the cylinder which is adjacent to the carrier moves upwards, ſo as to carry up the wool it has taken from the carrier, and give it to the workers 2 *a* and clearers 2. The ſurfaces of the workers 2 *a* move in the ſame direction as the ſurface of the great cylinder, but they turn ſlowly, being put in motion by the chain 9, which paſſes over wheels at the ends of all the three workers. Theſe wheels have cogs or teeth to enter into the links of the chain, and prevent it from ſlipping; the chain paſſes beneath a wheel fixed on the axis of the cog-wheel E, but withinſide the frame. The wheel E is turned by a pinion 8, fixed on the extremity of the axis of the great cylinder; and the proportions are ſuch, that the workers 2 *a* revolve once to about four turns of the great cylinder, and the workers being about 6½ inches diameter, whilſt the cylinder is 30 inches diameter, the ſurface of the cylinder moves about 18½ times as faſt as the ſurfaces of the workers.

The ſmall rollers 2, called clearers, are placed ſo as to card the wool on the workers, and on the great cylinder alſo. The clearers are turned round very quickly, and take the wool from the workers, but their ſurfaces do not move ſo faſt as the ſurface of the cylinder. Thus the ſtrap 13 paſſes over a wheel of about 8½ inches diameter, fixed on the extremity of the axis of each clearer; this ſtrap is put in motion by a wheel of about 22 inches diameter, fixed on the axis of the great cylinder; therefore, the clearers turn about 2½ times to one of the great cylinder; but as they are only 3¼ inches diameter, and the great cylinder is 30 inches diameter, the ſurface of the cylinder moves near 3½ times as faſt as that of the clearer. The carrier 4 *a* is turned by the ſame ſtrap 13; but being larger than the clearers, its ſurface moves much quicker, ſo that the cylinder's ſurface moves only about once and a half as faſt as the carrier's ſurface.

The ſtrap 13 alſo turns a cylinder 2, at the right-hand end of the machine, called the fly: its ſurface moves the ſame way as the ſurface of the cylinder, but moves nearly once and a half as faſt; the pulley at the end of the fly being only 4½ inches diameter, and the fly itſelf nine inches. The fly is not placed ſo cloſe to the cylinder as to take the wool away therefrom, but is intended to raiſe and looſen it in the cards of the cylinder, ſo that the cylinder 4 beneath it, called the doffer, can take off the wool more readily. This doffer is 14 inches diameter, and is covered with ſeparate ſheets of card-wire, each about 4 inches wide, leaving vacant ſpaces between them parallel to the axis of the cylinder. The doffer moves round very ſlowly, its ſurface moving only $\frac{1}{30}$ of the velocity of the ſurface of the cylinder: it is turned by a band from a pulley on the axis of the roller D, which we ſhall next deſcribe.

The comb which works againſt the ſurface of the doffer, and ſtrips off the wool from it, cannot be ſeen in the drawing. The comb is ſupported by two upright rods, ſcrewed to it one at each end; the upper ends of theſe rods are guided by two horizontal levers, and the lower ends are jointed to two ſmall cranks formed on an horizontal axis, which is ſituated at the lower part of the frame near the ground, and put in rapid motion by a ſtrap, from a pulley at the bottom of the frame beneath the great cylinder. This pulley has a ſmaller one fixed on the extreme end of its axis, and receives its motion from the ſame ſtrap 13, which turns the clearers. Every revolution of the cranks cauſes the comb to riſe and fall about two inches; and when the comb deſcends, the teeth on its edge act againſt the cards, on the ſurface of the doffer 4, ſo as to take out the wool from them. This wool is ſeparated in a continued ſheet or film, becauſe the ſtrokes of the comb ſucceed each other very quickly, and the doffer turns round ſlowly; but owing to the vacant ſpaces between the cards on the doffer, this film only continues for a width of about four inches, and is then diſcontinued until the vacant ſpace on the doffer has paſſed by the comb, which then acts again to ſtrip off the wool, and ſo on: hence the wool is drawn off from the machine in a carded ſtate, in ſmall and very delicate films or webs of about 4 inches wide, and 27 or 28 inches long, which is the length of the doffer.

Theſe detached portions of wool are next rolled up ſo as to form ſmall cylindrical rolls, which is done by what is called the roller-bowl D: it is a cylinder of wood, with ſhallow flutes upon its ſurface, parallel to its axis; it is turned round ſlowly by a pulley H on the end of its axis, and an endleſs band, 14, which paſſes round a pulley I, fixed on the wheel E. The lower part of the roller-bowl, D, is incloſed within a hollow cylinder of wood, called the ſhell; it encompaſſes the lower half, being fixed beneath the revolving cylinder; the ſhell is fluted within ſide, but does not touch the bowl, leaving a ſmall interval between the two. The portions of wool, as they are ſtripped or combed off from the doffer, fall down over the edge of the ſhell, which for that purpoſe is ſituated cloſe to the doffer, at that part of its circumference where the comb works: by this means, the wool which is ſtripped off falls down into the ſpace between the ſhell and the roller-bowl; and when the portion of wool is completely detached and drops off, the motion of the bowl within its ſhell rolls the wool between them with a rolling motion, which forms the wool into a very round and ſtraight cylindrical roll, called a carding, when theſe cardings drop out from between the roller-bowl and its ſhell; they fall upon a flat table, *a a*, as ſhewn at 7 7 7. This table is covered with an endleſs cloth, which is ſtretched over two horizontal rollers; one of theſe rollers has a croſs, marked 16, 16, fixed on the end of its axis; the arms of the croſs are ſeized by a cranked lever, 15, which is fixed to the axis of the roller-bowl, and at every revolution the croſs 16 is turned round one-fourth: this moves the endleſs cloth forwards, and carries the cardings away in the manner ſhewn at 7 7 7, as faſt as they drop out from the ſhell, and from this table they are carried away to the ſlubbing-machine, or billy.

In moſt modern machines the latter movement is altered, the endleſs cloth being kept in a continual and ſlow motion by an endleſs band paſſing round a ſmall pulley fixed to the pulley H, and a larger pulley fixed in place of the croſs 16.

In ſome old carding-engines many of the motions were performed by toothed wheels and pinions; but of late years all the parts are moved by bands or ſtraps, which produce a much more equable and ſteady movement. The large cylinders are generally made by placing two or more wheels of caſt iron on one axle, the circumference of the wheels being caſed with wood, which is attached to them by ſcrews or rivets. The ſmaller rollers are formed in a ſimilar manner on wooden diſks, but all are made hollow, to avoid warping, which would render the action of the cards irregular and uncertain.

We muft now return to the fcribbling-machine: it is the fame as the carding-machine, except that the breadth of the cylinder is greater, and the teeth are coarfer; there is no roller-bowl D, and the doffer 4 is completely covered with cards, without any breaks or intervals; hence the film of wool which is taken off is continuous, and is fuffered to fall down into a bafket.

Double Scribblers.—In Yorkfhire it is common to employ double fcribblers; that is, two of the machines combined together, and placed in one frame; there are two large cylinders, each furrounded with its workers and clearers, and doffer, as we have defcribed, making in all feventeen fmall cylinders. The firft great cylinder has a feeding-cloth and carrier, to fupply the wool to the cylinder; but the fecond large cylinder is fupplied with wool from the doffer of the firft cylinder, which doffer ferves in place of a carrier to the fecond; it therefore has no comb. The doffer of the fecond cylinder has a comb to take off the wool, which then falls into a bafket.

This machine is faid to fave trouble of attendance, and does more work than two fingle machines. The ufual practice is to pafs the wool once through the double machine, and then once through a fingle machine. A double machine will fcribble about a hundred weight of wool *per* day.

After the wool is fcribbled it is weighed, and when it is taken to the carding-machine, a certain weight is fpread over a certain length of the feeding-cloth, fo as to fupply the wool to the machine with perfect regularity. The proper weight which fhould be allowed is afcertained experimentally, according to the finenefs of the thread which is required to be fpun. The cardings are weighed from time to time, to afcertain if each one contains the proper quantity of wool.

The cardings produced by the united operations of fcribbling and carding are compofed of fibres of wool laid very lightly together with the leaft poffible entanglement; they are very regular and even in fize, and upon this circumftance the perfection of the fpinning chiefly depends.

Slubbing-Machine, or Billy.—This performs the firft procefs of fpinning. It reduces the cardings, and draws them out in length; joins them together, and gives them a flight twift, in order to form a coarfe and loofe thread, called a flubbing or roving, which muft be fpun over again in the jenny, to make a thread fine enough for the loom.

This operation was formerly performed by hand on the common hand fpinning-wheel, which is fimilar to that ufed for fpinning wool, but of a fmaller fize. Machines were then contrived by which a number of flubbings could be drawn out together; but the aid of the hands was required for joining the rolls or cardings of wool together in fucceffion, and for other purpofes, which were found to take fo much time, that very little, if any, faving of labour was effected by the ufe of fuch machines.

A perfpective view of the flubbing-machine, now univerfally employed, is given in *Plate* I. *Woollen Manufacture.* A A is the wood frame of the machine; within this frame is a moveable carriage, D D, which runs upon the lower fide-rails at *a a*, with wheels 1, 2, to make it move eafily; and it is capable of running backwards and forwards in the frame from one end to the other. The carriage contains a number of perpendicular fpindles, marked 3, 3, which are put in rapid motion by a long cylinder F, and a feparate band from each fpindle, which paffes round a fmall pulley on the fpindle. The cylinder F extends horizontally acrofs the whole breadth of the carriage; it is made of tin plate, hollow like a tube, and covered with paper on the outfide.

The fpindles are placed in a frame, fo as to ftand nearly perpendicular, at about four inches from each other; their lower extremities are fharp-pointed, and turn in fockets, and they are retained in their perpendicular pofition by a fmall collar of brafs for each, which furrounds the fpindle at about the middle of its length. The upper half of each fpindle projects above the frame, and on the lower part the fmall pulley or whirl is fixed, to receive the band from the horizontal cylinder, which is about fix inches in diameter, and a little longer than the row of fpindles; it is placed before them with its centre at a lower pofition than the row of whirls. The cylinder receives motion by a pulley at one end, with an endlefs band from a wheel E, made like the large wheel ufed in fpinning wool by hand, and of the fame dimenfions. The wheel is fituated at the outfide of the great frame of the machine, and its axis is fupported by upright ftandards erected from the carriage D; the wheel is turned by the left-hand of the fpinner, applied to a winch, which is plainly feen in the drawing, and gives motion to the cylinder F, which again turns all the fpindles at once with a great velocity.

Each fpindle receives a thread, or flubbing, which threads iffue from beneath a roller, C C, at one end of the frame, and proceed to the row of fpindles placed in the carriage, fo that the flubbings are extended nearly in an horizontal direction. The fpindles, by the motion of the carriage, are capable of advancing or retreating from the roller C, fo as to extend any required length of flubbing.

The cardings of wool, which are to be fpun into flubbings, are extended fide by fide upon an endlefs cloth, which is ftrained in an inclined pofition between two horizontal rollers, one marked B B, and the other cannot be feen. There is one carding for each fpindle, and the number is ufually from 50 to 80. C is a light wooden roller to bear upon the cardings which lie upon the cloth, and prefs flightly upon them by its weight. Immediately before this roller is a wooden rail G, and another beneath it, which is fixed horizontally acrofs the frame: the cardings are conducted between thefe two rails, the upper of which is capable of rifing; but when it falls by its weight, it holds the cardings faft between the two, and hence thefe rails are called the clafp; the upper moveable rail G of the clafp is guided between fliders, and a wire 7 defcends from it to a lever 6. When the carriage D is wheeled clofe home to the end of the machine, a wheel 5 lifts up the end 6 of the lever; and this, by the wire 7, raifes the upper rail G fo as to open the clafp, and releafe all the cardings: in this ftate, if the carriage is wheeled or withdrawn back from the clafp, it will draw the cardings forward. There is a fmall catch which receives the upper rail G of the clafp, and bears it up from falling until the carriage has retreated a certain diftance, and drawn out about eight inches length of the cardings; a ftop on the carriage then comes againft the catch and withdraws it; the upper rail of the clafp G then falls and holds the cardings faft, whilft the carriage continues to recede, and draw out or ftretch that portion of each carding which is between the clafp and the fpindle. All this time the wheel is turned to keep the fpindles in motion, and give twift to the cardings in proportion as they are drawn out, by which means it is prevented from breaking; becaufe as the carding diminifhes in fize, and increafes in length, the increafing twift combines the fibres of the wool, fo as to give ftrength to the coarfe thread or flubbing which is thus produced.

The flubbing is lapped round the fpindle, but the clafp being higher than the upper ends of the fpindles, the direction of the flubbing is not quite at right angles to the fpindle; hence the fpindle, when it is turned round, will give twift to the flubbing, without winding or gathering it

up upon the ſpindle, becauſe the ſlubbing always ſlips over the top-end of the ſpindle; but when a portion of each ſlubbing is finiſhed, and it is required to wind it up round the ſpindle in a ball, the ſlubbing muſt be preſſed down by a wire 8, ſo as to bear it from the point of the ſpindle, and place it oppoſite to the middle part of the cop or ball upon the ſpindle, and then the motion of the ſpindle will cauſe it to wind up upon the ſpindle, and form a ball.

The wire 8 is made to operate upon the whole row of ſlubbings at once, and for this purpoſe a horizontal rail 4 is placed in the front of the row of ſpindles, being provided with pivots at its extreme ends, on which it is ſupported in ſtandards riſing from the carriage D. It has a ſmall arm or lever projecting from it at each end, and the wire 8 is ſtretched between theſe arms. By turning the rail 4 round upon its pivots, the wire is capable of being raiſed up, as in the figure, or lowered down at pleaſure: when the wire is lowered, it deſcends below the level of the top of the ſpindles, ſo as to bear down the threads which, when the wire is raiſed up, as ſhewn in the figure, proceed from the points of the ſpindles.

The ſpinner holds the rail 4 in his right-hand, and it is by this that he draws the carriage either in or out, according as it may require; and by turning the rail 4 round, he can elevate or depreſs the wire 8, ſo as to make it bear down the ſlubbings to any degree at pleaſure; by this means, he diſtributes the ſlubbings upon the ſpindles in a proper manner, to form a regular ball or cop, as ſhewn in the figure.

As the cardings are very ſlight and tender, they would be liable to break if they were dragged forwards on the inclined cloth, or even if the cloth were to be moved round its roller by the force applied to the cardings. To avoid this, a cord is applied round a groove in the middle part of the upper roller, and after paſſing over proper pulleys, as ſhewn in the drawing, it has a weight ſuſpended to one end, and a ſmaller weight to the other; the ſmall weight is only to keep the rope tight, but the large weight tends to turn the rollers and endleſs cloth round in a direction to deliver out the cardings, ſo that there will be no ſtrain on them. Every time that the carriage is wheeled home, the large weight is wound up by means of a piece of wood projecting from the carriage, which ſeizes a knot in the cord at the part which lies horizontally; this puſhes the cord back a certain diſtance, ſo as to draw up the great weight; but the endleſs cloth cannot turn backwards, becauſe there is a ratchet and click at one end of the roller which prevents it; the rope, therefore, ſlips round upon the roller. When the carriage retires, the great weight turns the roller and endleſs cloth round, ſo as to deliver out the cardings at the ſame rate as the carriage retreats and takes them up; but when the proper quantity is given out, the knot in the rope arrives at a fixed ſtop, which does not permit it to move any farther; and at the ſame inſtant the roller 5 quits the lever 6, and allows the upper rail G of the claſp to fall, and hold the carding faſt from being drawn out any farther; the wheel E is then put in motion to turn the ſpindles round, and the carriage is drawn back, which extends the ſlubbings, and twiſts them at the ſame time, as before mentioned.

When the carriage is drawn out to its full extent, and the neceſſary twiſt is given, the wire 8 is put down to bear down the ſlubbing from the point of the ſpindle, and the motion of the wheel being continued, the ſlubbings are wound up upon the middle part of the cop or ball which is formed upon the ſpindle; but as faſt as the ſlubbings are wound up, the ſpinner muſt puſh back the carriage towards the claſp; and he muſt turn the wheel round at ſuch a rate that the ſpindles will not wind up any faſter than the carriage returns, otherwiſe the ſlubbings would be broken or unequally ſtretched; he muſt alſo raiſe and lower the wire 8 continually, by turning the rail 4 round in his hand, in order to diſtribute the ſlubbing on the cop in a regular manner, ſo as to make a firm ball or cop.

A child attends the machine to bring the cardings from the carding-machine, and place them upon the inclined cloth; and when they are exhauſted, freſh ones are joined on, ſo as to keep the machine conſtantly ſupplied.

The degree of twiſt which is given to the ſlubbing is regulated by the diſcretion of the ſpinner in turning the wheel at a proper rate, correſponding to the quickneſs with which he draws out the carriage. Slubbings which are intended to be ſpun into yarn for the warp of the cloth require to be more twiſted than the ſlubbings intended for the weft; but the proper quantity of twiſt depends on the fineneſs of the wool, and the length of its fibres. In general it may be ſtated, that no more twiſt is given to the ſlubbings than is neceſſary to make them draw out to the required extent without breaking. This twiſt is of no uſe to the yarn, becauſe the ſlubbing will be twiſted in the contrary direction, when it is ſpun the ſecond time in the jenny.

An improved ſlubbing-machine has been introduced, which is put in motion by the mill, and the carriage is made to draw out by the power of the machine. The ſpinner has only to puſh the carriage in, and turn the handle, in order to wind up the ſlubbings; by this means, a greater degree of regularity is attained in the quantity of twiſt which is given to the ſlubbings when they are drawn out. The movements to effect this are taken from the mule uſed in cotton-ſpinning. See *Manufacture of* COTTON.

Spinning Jenny.—In this machine, the ſlubbings are ſpun over again, and reduced to the requiſite fineneſs for weaving. The jenny has nearly the ſame parts as the billy, but differently arranged. The ſpindles are placed at one end of the frame, and the claſp which holds the ſlubbings is placed on the carriage, ſo that it can be moved backwards and forwards, to and from the ſpindles by the ſpinner, in order to draw out and extend the yarn at the ſame time it is twiſted.

A perſpective view of the jenny is given in *Plate* II. *Woollen Manufacture.*

The ſpindles 3, 3, 3, are placed perpendicularly at about four inches aſunder at one end of the frame A A of the machine. The lower extremities of the ſpindles are pointed, and turn in ſmall cups or ſockets in a croſs-rail of the frame; they are ſupported near the middle of their length by paſſing through braſs-collars in a horizontal rail. Near the lower end of each ſpindle a ſmall pulley is fixed, to receive an endleſs band, which paſſes round the horizontal cylinder or roller 2, about ſix inches diameter. The cylinder is ſupported on pivots at its ends in the ſides of the frame, and lying in a direction parallel to the row of ſpindles, it turns them all round by a ſmall band for each. This cylinder is uſually made of tin-plate, that it may not alter its figure by the weather, as wood would do; and its ſurface is covered with coarſe brown paper, to prevent the bands from ſlipping upon it. The cylinder 2 is put in motion by a ſtrap or band 1, 1, which paſſes round a pulley at the end of it, and alſo round the great wheel B B, which is ſupported in a framing ſuſpended over the machine from the ceiling, but which is not ſhewn in the drawing. The wheel B is turned by applying the right-hand to the winch B. In front of the row of ſpindles, and about a foot higher than their points, a long croſs-rail 16 is ſituated horizontally: it is ſupported at each extremity by being mortiſed into blocks of wood *c c*, which are furniſhed

with ſmall wheels or caſtors, forming a ſort of carriage, to run horizontally upon the ſide-beams of the main-frame in grooves, which guide them, ſo that the rail 16 can be moved backwards and forwards through a ſpace of about ſix or ſeven feet, in a horizontal poſition, without varying from its parallelism with the row of ſpindles. The underſide of the rail 16 is formed into a number of narrow notches for the ſlubbings to paſs through; and theſe notches are partly filled up by projecting pieces, riſing up from a ſecond croſs-rail 5, 5, ſo as to form the claſp which confines or pinches the ſlubbings in the notches when the lower rail is raiſed up; but the ſlubbings can draw freely through the notches when the lower rail is let down. This lower rail is guided and limited to move up and down only a ſmall ſpace by ſtaples, which project downwards from the rail 16, and receive the ends of the lower rail 5 of the claſp. The riſing and falling of the lower rail is effected by ſmall cords faſtened to it at about every yard of its length; theſe cords are conducted over ſmall pulleys (concealed in the ſubſtance of the upper rail 16), and are all attached to a handle, ſituated over the middle of the upper rail at 16, and beneath an arched bar, which is fixed on the top of the claſp. The ſpinner holds this handle in the left-hand, whilſt the right is employed in turning the wheel; and by the fingers of the left-hand ſhe can raiſe up the lower rail 5 of the claſp, and draw it cloſe to the upper one. It will then be retained in that poſition by a ſmall ſpring-catch, and will claſp the ſlubbings faſt in the notches, through which they paſs; but when the ſpring-catch is puſhed back, ſo as to relieve the handle, the lower rail will fall down by its own weight, and releaſe the ſlubbings, to allow them to ſlide through the notches.

The cops of ſlubbings which are to be ſpun are ſupported in an inclined frame 4, 4, faſtened within the main frame of the machine. The cops are mounted upon iron wires; they are placed in two rows, one above the other, as ſhewn in the drawing; but each row ſhould only contain half as many cops as there are ſpindles.

Each ſlubbing is conducted through a notch in the claſp, and thence it proceeds nearly in an horizontal poſition to the ſpindles 3, 3.

When the yarns have been drawn out and twiſted they are wound up on the ſpindles in balls, in a ſimilar manner to the billy. The wire which is uſed for bearing down the thread from the points of the ſpindles is marked 12; it is attached to a horizontal rail, which is ſupported on pivots at its ends, cloſe to the row of ſpindles. There is a ſmall pulley 11, fixed at one end of the rail, and a ſhort lever at the other, which lever is hidden in the drawing by a part of the framing. Between the pulley 11 and the lever, the wire 12 is extended, and by turning the rail round upon its pivots, the wire will have a motion up or down.

The ſpinner can communicate motion to the pulley 11 by means of a cord 7, 7, which paſſes round it, and extends the whole length of the frame, the end being made faſt to a pin at A; this cord lies over the ſurface of one of the blocks *c*, which contains the wheels of the carriage, and paſſes between three ſmall pulleys 9, 6, and 8. The centre pins of the pulleys 9 and 8 are fixed to the block; but the centre pin of the pulley 6 is fixed to a ſmall ſlider, and can be drawn in the direction of the rail 16, by applying the finger to a ſmall trigger near the handle 16. This action removes the pulley 6 out of the line of the other two pulleys, ſo as to ſhorten the cord 7, and turn round the pulley 11; this brings down the wire 12, and bears down the threads upon the ſpindles. A ſmall counterweight is ſuſpended from the wheel 11, to return the wire to its former poſition when the preſſure of the finger on the trigger is removed. By this movement, the ſpinner has full command of the wire 12, to raiſe or lower it in any degree ſhe thinks proper; and this is done independently of the motion of the carriage, becauſe the pulleys 9, 6, and 8, run freely along the cord 7, and their motion has no tendency to move the wheel 11 either way.

The jenny is worked by one perſon, who ſtands within the frame, and turns the wheel B with the right-hand, whilſt he holds the claſp in the left, ſo as to run it backwards and forwards along the frame at pleaſure. The ſlubbings are drawn between the moveable rails 16 and 5, in the notches of the claſp, and each ſlubbing is faſtened on to its correſponding ſpindle. The claſp being left open is drawn backwards from the ſpindles, and the ſlubbings run freely through the notches of the claſp; the ſlubbings are drawn off the balls at 4, when the claſp retires from the ſpindles, until a certain length of each ſlubbing is drawn out and extended nearly in an horizontal poſition between the ſpindles and the claſp: this length is regulated by a mark made on the frame of the machine, to indicate when the claſp has arrived at its proper poſition. The bars of the claſp are then brought together by raiſing up the handle under the catch, as before deſcribed, and it faſtens all the ſlubbings in the notches. This being done, the ſpindles are put in rapid motion by turning round the large wheel B B; they twiſt thoſe parts of the ſlubbings which are extended, and the motion being in a contrary direction to the twiſt of the ſlubbing, the firſt tendency is to untwiſt the ſlubbing, at the ſame time that the carriage and claſp are gently drawn back, or from the ſpindles. By this means, the ſlubbings are ſtretched or drawn out in length at the ſame time that they get a new twiſt in the oppoſite direction; this keeps them from breaking, and when they are drawn to their intended extent by the carriage being moved back to the ſtops at the extremity of the main frame, the great wheel is turned round as many turns as is neceſſary to give them all the twiſt which thoſe portions of thread are intended to have.

The threads extended between the claſp and the ſpindles are now finiſhed, and it only remains to wind them up upon the ſpindles, previouſly to drawing out a freſh portion of each ſlubbing, in order to ſpin it in the ſame manner. To wind up the threads, they are puſhed down upon their reſpective ſpindles, by preſſing the trigger which moves the wire 12; and the motion of the great wheel B is continued, in order to wind up the ſlubbings in balls upon the ſpindles, at the ſame time that the carriage and claſp are puſhed back towards the ſpindles. When the carriage is got home, the thread is finiſhed and wound up, and a freſh portion of ſlubbing is extended. To do this, the lower rail of the claſp is dropped down, and it releaſes the ſlubbings; the carriage is then drawn back to the mark upon the frame, as before deſcribed, which ſhews that a proper length of each ſlubbing is drawn off from the balls, and extended between the ſpindles and the claſp. The claſp is then cloſed, and the wheel B put in motion to twiſt the threads whilſt the carriage is drawn out; thus the ſpinning operation is repeated as before, and prepares another length of each of the threads. When finiſhed, they are puſhed down from the points of the ſpindles, in order to make them wind up thereon in the balls, as before.

There is ſome diſcretion required in ſpinning with the jenny, to draw out the carriage with a movement correſpondent to the rapidity with which the ſpindles give the twiſt, or rather untwiſt, to the ſlubbing; for the principal extenſion of the thread is effected whilſt the ſlubbing is untwiſting, and whilſt the firſt portion of twiſt is given to the threads. Theſe motions muſt be properly proportioned by

the ſpinner, who muſt alſo be careful to give an equal degree of twiſt to each ſucceſſive portion of thread which is ſpun, otherwiſe the thread will conſiſt of hard and ſoft places.

When the yarn is intended for the warp of the cloth, the ſpindles are turned for a given time after the thread is extended to its full length, as we have before mentioned; but for the yarn which is to be uſed as weft, it is different: the whole of the twiſt is given during the extenſion of the thread, and none afterwards; this difference is to render the weft ſofter than the warp, becauſe in the cloth the weft appears more on the ſurfaces than the warp, and it is principally the felting and interlacing of the fibres of the weft that will form the ſurface of the cloth when finiſhed.

The yarns are uſually extended in the jenny two and a half or three times the length of the ſlubbings from which they are ſpun; and that degree of twiſt given to them which is ſuitable to the purpoſe for which the yarn is to be employed.

The *Mule for ſpinning of Yarn* is very nearly the ſame machine as the mule for ſpinning cotton; this is uſed for ſpinning ſome kinds of woollen yarn inſtead of the jenny. When the mule is employed for ſpinning yarn for weft, it is uſed in the ſame manner as deſcribed in our article Cotton *Manufacture;* but for ſpinning warp, the ſpindles are made to revolve, and twiſt the thread ſome time after the carriage is run completely out, and the ſtretching of the yarn is finiſhed. There is a movement in the machine that ſhifts the endleſs ſtrap which turns the mule upon a larger pulley, as ſoon as the carriage is run fully out, ſo as to give a more rapid motion to the ſpindles after the ſtretching, or drawing out, is finiſhed, than they had during the drawing back of the carriage. By this means ſome time is ſaved, becauſe the ſpindles may be allowed to run very quick when it is only required to twiſt the threads; but whilſt the extenſion is going on, the twiſting motion muſt be moderate, or the threads would be broken. A very ſimilar movement is uſed in the mule for ſpinning cotton, and is called the double-ſpeed; but the deſcription of this mechaniſm is omitted in the article Manufacture.

The mule has not, till lately, been in much repute for ſpinning woollen yarn, and the jenny is ſtill thought to ſpin better yarn: but we have no doubt that when certain modifications are made, it will become a much more perfect method than the jenny, being much leſs dependent on the diſcretion and dexterity of the ſpinner; for if the machine is once conſtructed ſo as to ſpin properly, it will always continue to do ſo.

To keep the yarn to the ſize which is intended, a few of the coppins are reeled off, in order to meaſure out a certain length of the yarn, which is weighed; and if it does not prove of the weight expected, the quantity of wool which is ſpread over a given ſurface of the feeding-cloth of the carding-machine muſt be increaſed or diminiſhed accordingly; and when the right quantity is formed, the lead weights which are uſed for weighing the given quantity of wool are altered to ſuit it. The draft of the jenny may alſo be altered to effect the ſame thing.

The ſpinning proceſſes are now finiſhed, and it remains to weave the yarns into cloth. From the deſcription we have given, it will appear that woollen yarn is ſpun in a very different manner from cotton. The opening proceſſes and the ſcribbling and carding are very ſimilar, except that the carded wool, inſtead of being drawn into a continued ſliver like cotton, with the fibres ſtretched the lengthways of the ſliver, is formed into ſeparate rolls, with the fibres diſpoſed croſſwiſe or ſpirally round the roll.

By the ſlubbing-machine theſe are joined together, drawn out in length, and ſlightly twiſted, by operations ſimilar to that of roving in cotton-ſpinning; but the operation of drawing, which is ſo frequently repeated for cotton, would be uſeleſs, and to a certain extent even prejudicial for wool. The object of that proceſs is to elongate and ſtretch the fibres of the cotton ſtraight, and lay them parallel to each other; but it does not reduce the ſliver to a ſmaller ſize, becauſe as many times as the ſliver is extended in length, ſo many ſlivers are put together into the drawing-frame at once, leaving the ſliver which has been drawn the ſame ſize as it was before, but elongated to three or four times the length, and all its fibres fully extended.

As woollen cloth is intended for felting, it is not deſirable to ſtraighten the fibres, but only to diſentangle all knots, and unfold any fibres which may be doubled, alſo to lay the fibres in the direction of the length of the thread. There is a natural curl in the fibres of wool which ſhould be preſerved, and will contribute to the firmneſs with which the fibres will entangle in the felting.

The operation of ſpinning by the jenny and billy are very ſimilar, but both differ from the manner in which the extenſion is made in the cotton ſpinning-machines by rollers. In the jenny, the extenſion is made upon a conſiderable length of the carding or ſlubbing at once; but in the rollers, the length of cotton which is ſubmitted to the action of drawing out is very ſhort, indeed very little longer than the length of the fibres of the cotton. In mule ſpinning both modes of extenſion are practiſed; firſt, drawing the roving by rollers, and then a certain length is ſtretched out to a greater extent.

Warping.—The coppins of yarn are mounted on wires in a frame, and the yarns are drawn off from them, in order to combine a ſufficient number of them together, to form the warp for the web of cloth which it is intended to weave. For inſtance, for making the cloth called double drab, which we ſhall take as an example, 2960 threads, each 65 yards long, are laid parallel to each other; but a ſeparation is preſerved at every 40 threads, dividing the whole into 74 parcels, for the convenience of the weaver.

The warping is performed by the warping-mill, which is a large reel, with its axis horizontal; the ends of the threads are made faſt to the reel, which is turned round, and it draws the threads off the coppins, ſo as to wind them upon its circumference; and to prevent the different turns of the threads from lying one over another, the threads are guided through an eye or ring affixed to a ſlider, which is moved along a wooden rail, in a direction parallel to the axis of the reel, by a cord that winds round one end of the axis of the reel.

A warping-mill for ſilks is deſcribed in our article Silk, and will give a clear idea of the preſent, which only differs in the horizontal poſition of the axis, and in the greatneſs of its dimenſions. The threads for the warp being thus aſſembled together, are taken off the reel, and rolled up into a bundle.

The warp is then ſcoured in urine, to remove the greaſineſs of the wool, and is next ſized; to do this, it is dipped into the cauldron of ſize, about ten yards in length at a time, and well worked in by the hands. After ſizing, the yarns are ſtretched out at length in a field, till they are dry, and the warp is then ready for the loom.

The yarn for the weft is wound off from the cops of the jenny to the quills or ſmall bobbins, which are to be put into the ſhuttle.

The loom for weaving broad-cloth has the ſame parts as the ſimple loom deſcribed in our article Weaving; but it is made very ſtrong, to enable it to reſiſt the ſtrain of weaving

ſuch broad and heavy cloth. The fly-ſhuttle, invented by John Kay in 1737, is now in general uſe; it enables one weaver to do the work, which formerly employed two men at oppoſite ſides of the piece, to throw the ſhuttle from one to the other, the width being greater than a man can reach. The warp is wound on the yarn-beam, which is placed in the loom, and the threads being drawn through the heddles and the reed, and faſtened to the cloth-beam, the loom is ready for working, in the uſual manner of weaving plain cloth. At each edge of the warp a few threads of ſtrong and coarſe yarn are placed; theſe form what are called the lifts when the cloth is woven, and ſerve to give ſtrength to the cloth, and receive the hooks by which the piece is ſtretched in the tenters after milling.

The width of the cloth is meaſured between the lifts and the number of yarns, which we have ſpecified will make 100 inches in width for the double drab-cloth, or for common cloth 3000 threads will make a piece $103\frac{1}{2}$ inches wide. The quantity of weft uſed for theſe cloths is upon an average one pound weight to a yard in length. The length of the warp contracts a little in the weaving, ſo that the ſixty-five yards of yarns will make only ſixty-two yards of cloth.

Scouring.—The piece of cloth muſt be cleanſed from the greaſineſs of the oil before it can be felted; for this purpoſe, it is firſt ſoaked three hours in a mixture of urine and pig's dung, it is then ſcoured in the mill for two hours, and laſtly, for half an hour with fair water. The ſcouring is performed at the fulling-mill by a pair of ſtocks. (See FULLING-*Mill.*) The pair of ſtocks are two large wooden hammers, ſuſpended with the helves or handles in an inclined poſition, and the heads are lifted in ſucceſſion by cogs or tappets, fixed on the axis of a water-wheel. When the cogs quit the hammers, they fall by their own weight, and ſtrike the piece of cloth, which is contained in a wooden ciſtern or trough, in which the hammers work. The action of the hammers is to beat and compreſs the folds of cloth, and to turn the piece continually round in the trough or ciſtern in which it is placed. The form of the trough is ſuch, that the weight of the piece of cloth cauſes it to occupy the lower part of the trough, and each hammer when it deſcends drives the cloth out from this loweſt part, and forces it up a curved ſweep. When the hammer is lifted up, the cloth falls again into the ſpace which it before occupied, and at the ſubſequent deſcent of the hammer it is again driven out; the heap of cloth is of a conſiderable bulk, and this action of the hammers is chiefly on the lower part of the heap; the beaks of the hammers ſtrike nearly horizontally under it, as it were to undermine the heap, ſo that the top part falls over when the hammers retreat. This action cauſes a continual circulation or turning round of the piece of cloth within the trough, and effects the ſcouring, by continually bending and folding the cloth in a freſh direction; and as the ſtrokes act upon a great number of folds at once, the different ſurfaces of the cloth are cauſed to rub againſt each other, with a very ſimilar action to waſhing cloth by hand.

When the ſcouring is finiſhed, the piece of cloth is taken out, and extended in a vertical plane, in a frame called the tenter, where it remains till dry.

The *tenter* conſiſts of a number of vertical poſts fixed in the ground with a continued horizontal rail, which is fixed on the top of them, and is as long as the piece of cloth; there is alſo another line of horizontal rails, which are fitted between the upright poſts, ſo as to ſlide freely up and down; and they can be fixed at any diſtance beneath the upper rails by means of pins in the poſts, according to the width of the piece of cloth. Both the upper and lower horizontal rails are driven full of tenter-hooks, which are ſmall iron rails ſharpened at both ends, and bent at right angles, like an L; on theſe hooks the lifts of the cloth are faſtened, and the lower or moveable rails are fixed at the proper diſtance beneath the upper rails, in order to extend the cloth to its full width.

Burling.—The cloth being dried is burled, that is, examined minutely in every part, and all knots and uneven threads or ſtraws, or extraneous matters, removed; any rents or defects which can be found are repaired, by introducing freſh threads. This being done before the milling or felting, the fibres of the new threads will become ſo entangled as to render ſuch defects nearly imperceptible in the finiſhed cloth.

Fulling-Mill for felting the Cloth.—There is another kind of ſtocks in a fulling-mill; but the ſhape of the trough in which the ſtocks or hammers work on the cloth is different from that deſcribed in the article FULLING-*Mill*, which is only proper for ſcouring. In order to ſubject the cloth to the blows of the hammers, the trough for milling is formed in ſuch a manner that the cloth cannot eſcape from them, becauſe that part of the trough which is oppoſed to the beaks of the hammers is nearly a flat ſurface, and perpendicular to the direction in which the hammers ſtrike, ſo that the cloth is actually beaten between the beaks of the hammers and the flat bottom or rather ſide of the trough.

The hammers are made to ſtrike very heavy blows; but they do not bruiſe or injure the cloth, becauſe there is always a great number of folds of cloth on which they ſtrike. The helves or handles of the hammers are placed in a different poſition from the ſcouring-ſtocks, in order to make the hammer-heads fall in a more perpendicular direction when they make their ſtroke, and hence they ſtrike with more force. On this account they are called falling-ſtocks, whilſt thoſe uſed for ſcouring are called hanging-ſtocks, in which the helves of the hammers being nearer to the perpendicular, the heads move in a more horizontal direction, in the manner of a pendulum, and exert leſs force on the cloth; the other difference is, that the hammers of the ſcouring-ſtocks only drive the heap of cloth round in the trough, there being no part directly oppoſed to the beaks of the hammers but a fair curve, which is ſo much inclined to the direction in which the hammers move, that the cloth mounts up the inclined curve when the hammer ſtrikes, and evades the direct force of the blow.

There is another kind of fulling-ſtocks, in which the trough and hammer are conſtructed with a view to mill or felt the cloth; but the hammers are put in motion in a different manner: thus the helves are ſuſpended in a vertical poſition, like pendulums, and the force of the cogs on the horizontal ſhaft, which is turned by the water-wheel, is applied to drive the hammers forwards againſt the cloth, and produce the felting. To return or draw back the hammers, a chain is attached to each, and theſe chains are linked to the oppoſite ends of an horizontal lever, like a ſcale-beam, which is fixed in front of the ſtocks. This lever and chains draw back one hammer when the other is puſhed forwards; and as the hammers are actuated alternately by the cogs, a conſtant action is kept up.

The moſt ſimple fulling-mill by a water-wheel has no other wheels, but the tappets or cogs which lift the hammers are fixed immediately into the axis of the water-wheel, and it uſually gives motion to two pair, one at each ſide of the wheel. It rarely happens that this conſtruction of a mill allows the water to be uſed to the greateſt advantage, becauſe the circumference of a water-wheel ſhould not move with a greater velocity than between 180 and 240 feet *per*

minute; and the hammers of a fulling-mill ſhould be ſo timed, that each one will make from about 30 to 36 blows *per* minute. This requires that the cogs for the hammers ſhould be numerous, and fixed in the circumference of a large wheel fixed on the axis of the water-wheel, otherwiſe the water-wheel muſt be made to turn ſo quickly as to loſe a great part of its force. A better way is to apply a cog-wheel on the axis of the water-wheel to turn a pinion on the horizontal ſhaft, which carries the cogs for the hammers, and this horizontal ſhaft may have a fly-wheel upon it, to regulate the motion and render it uniform.

Mr. Smeaton's proportions for a fulling-mill for two pair of ſtocks were as follows:—The water-wheel, 14 feet diameter, 7 feet broad; it was a breaſt-wheel, and the fall of the water was five feet from the ſurface of the mill-pond to the tail-water below. The ſpur-wheel on the axis of the water-wheel 72 cogs, and 9½ feet diameter; the lantern turned by it 23 rounds. Upon the ſame ſhaft as this lantern was a fly-wheel of eight feet diameter, with a rim of caſt-iron ſeven inches ſquare, and alſo the two cogs or tappets for each of the four hammers forming two pair of ſtocks. The ſame mill was adapted to be turned by the power of horſes in dry ſeaſons; for this purpoſe, another lantern of 13 teeth was applied on the other end of the ſame horizontal axis, which could be occaſionally turned by a horizontal cog-wheel of 90 teeth and 12 feet diameter, fixed on the vertical ſhaft, which the horſes turned. The levers by which the horſes drew were 15 feet long, ſo that the horſes' track was 30 feet diameter.

It required four horſes to work one pair of ſtocks in this mill, and when Mr. Smeaton tried the expenditure of water at this mill, and alſo at another mill with an overſhot-wheel, he found it required from 1200 to 1400 cubic feet of water *per* minute, falling one foot, to work a pair of ſtocks. Taking the force of a horſe at 352 cubic feet *per* minute raiſed one foot, this is very nearly equal to four horſes. Theſe ſtocks were uſed for fulling of bays, and we apprehend the power for working the fulling-mills for broad-cloth is greater.

Proceſs of Milling.—A piece of cloth of fixty-two yards long has fix pounds of ſoap allowed for it, which is diſſolved in water, and a handful ſpread upon every yard in length; the piece is then put into the trough of the mill, and worked for three hours; during this time the cloth is frequently moved in the trough, to expoſe freſh ſurfaces to the action of the hammers. The blows upon the cloth cauſe a motion of the fibres of the wool amongſt one another, and the ſoap facilitates this motion; the fibres of the wool have the fingular property of moving always forwards in the direction of the roots of the hairs, when a number of hairs are rubbed or worked together, but they will not retreat in the oppoſite direction; this produces the matting or entangling of all the fibres together. After three hours milling, the piece of cloth is taken out of the trough, and ſoaped again, then returned and milled again for three hours. This is repeated four times, making twelve hours milling in the whole, and then a ſtream of fair water is admitted into the trough, to waſh away the ſoap. The piece of cloth, when taken out of the mill the laſt time, is generally found reduced to about 60 inches broad, and 40 yards in length; before the operation, it was 100 inches broad, and 62 yards in length.

The operation of felting is ſo well explained by M. Monge, in the Annales de Chimie, that we think proper to give an extract from his memoir, in addition to what is ſtated in our articles FELTING, FULLING, and WOOL.

If we examine a human hair, a fibre of wool, or the hair of a rabbit, hare, beaver, &c. in a microſcope of the greateſt magnifying power, the ſurface of each hair appears ſmooth and even; or at leaſt if any inequalities are perceptible, they ſeem rather to ariſe from ſome difference in the colour and tranſparency of particular parts of the fibres than from the irregularity of their ſurfaces; for their images, when viewed by a ſolar microſcope, are terminated by even lines, without any roughneſs. Nevertheleſs it is probable the ſurfaces of theſe objects are formed either of *laminæ*, which cover each other from the root to the point, much in the ſame manner as the ſcales of a fiſh cover the animal from the head to the tail; or ſtill more probably of zones placed one over the other, like what is obſerved in the ſtructure of horns; to this conformation it is, that ſuch ſubſtances owe their diſpoſition to what is called felting.

If with one hand we take hold of a hair by the roots, and draw it between two fingers of the other from the root towards the point, we are hardly ſenſible of any friction or reſiſtance, nor can we diſtinguiſh any ſound; but if, on the contrary, we draw it between the fingers from the point towards the root, we are ſenſible of a reſiſtance which did not exiſt in the former caſe. A ſort of tremulous motion is alſo produced, which is not only perceptible to the touch, but may alſo be diſtinguiſhed by the ear.

It is evident, therefore, that the texture of the ſurface of a hair is not the ſame from the root towards the point, as from the point towards the root. As this texture is the principal object of the preſent memoir, it is neceſſary to demonſtrate it by ſome other obſervations.

If a hair is held between the fore-finger and thumb, and rubbed by them backwards and forwards alternately in the direction of its length, a progreſſive motion of the hair will take place; but this motion is always with the root forwards, although the rubbing of the finger and thumb is alternately in both directions. This effect does not at all depend on the nature of the ſkin of the fingers, or its texture; for if the hair be turned, ſo that the point is placed where the root was, the movement then becomes contrary, *viz.* its motion is always directed towards the root.

What is obſerved in the above inſtance is entirely analogous to what happens when country children, by way of ſport, introduce an ear of rye between the wriſt and the ſhirt-ſleeve; the points of the beards of the ear are directed outwards, and by the various motions of the arm, this ear, ſometimes catching againſt the ſhirt, ſometimes againſt the ſkin, takes a progreſſive motion backwards, but the beards always reſiſt its return, ſo that it ſoon gets up to the arm-pit. It is very clear, that this effect is produced by the aſperities upon theſe beards, which being all directed towards the point, do not permit the ear to move in any other direction than towards that part which was united to the ſtalk. There can be no doubt that it is the ſame with reſpect to hair, and that its ſurface is beſet with aſperities, which being laid one upon the other and turned towards the point reſiſt all motion, except towards the root.

Theſe obſervations, which it would be uſeleſs to multiply, relate to long hair, which have been taken as examples; but they apply with equal propriety to wool, furs, and in general to every kind of animal hair. The ſurface of all theſe is, therefore, to be conſidered as compoſed of hard *lamellæ* placed one upon another, like tiles, from the root to the point; which *lamellæ* allow the progreſſive motion of the hair towards the root, but prevent a ſimilar motion towards the point.

From what has been ſaid, it will be eaſy to explain why the contact of woollen ſtuffs is rough to the ſkin, while that of cotton or linen cloths is ſmooth: the reaſon is, that notwithſtanding the flexibility of each particular fibre, the aſ-

perities upon the ſurface of the fibres of the wool, by fixing themſelves in the ſkin, produce a diſagreeable ſenſation, at leaſt till we are accuſtomed to it; whereas the ſurface of the fibres of hemp or flax, of which linen is made, being perfectly ſmooth, do not cauſe any ſuch ſenſation. It is alſo probable, that the injury ariſing to wounds or ſores from the application of wool does not proceed ſo much from any chemical properties, but is occaſioned ſolely by the form of the ſurface of the fibres, the aſperities of which attach themſelves to the raw and expoſed fleſh, which they ſtimulate and irritate to ſuch a degree as to produce inflammation.

The aſperities with which the ſurface of wool is every where ſurrounded, and the diſpoſition which it has to aſſume a progreſſive motion towards the root, renders the ſpinning of wool and making it into cloth difficult operations. In order to ſpin wool and afterwards to weave it, we are obliged to cover its fibres with a coating of oil, which, filling up the cavities, renders the aſperities leſs ſenſible; in the ſame way as oil, when rubbed upon the ſurface of a very fine file, renders it ſtill leſs rough.

When a piece of cloth is finiſhed it muſt be cleanſed from this oil, which, beſides giving it a diſagreeable ſmell, would cauſe it to ſoil whatever it came in contact with, and would prevent its taking the colour which is intended to be given to it by the dyer. To deprive it of the oil it is ſcoured at the fulling-mill, by working it with hammers in a trough full of water or urine, in which fuller's-earth is ſometimes mixed. This earth combines with the oil which it ſeparates from the cloth, and both together are waſhed away by the freſh water, which is afterwards brought to it in the machine. Thus after a certain time the oil is entirely waſhed out of the cloth.

The fulling, which ſucceeds the ſcouring of the cloth, is aided by the application of the ſoap. The alternate preſſure given by the hammers to the piece of cloth, eſpecially when the milling is pretty far advanced, occaſions an effect analogous to that which is produced upon hats by the hands of the hatter; the fibres of wool which compoſe one of the threads, whether of the warp or the weft, aſſume a progreſſive movement with their roots forwards, and introduce themſelves among the fibres of the threads neareſt to them, then into thoſe which follow; and thus by degrees all the threads, both of the warp and the woof, become felted together. The cloth, having by the above means become ſhortened in all its dimenſions, and thickened in its ſubſtance, partakes both of the nature of cloth and of that of felt; for at the ſame time that the threads give it conſiderable ſtrength, it may be cut without being ſubject to ravel, and on that account we are not obliged to hem the edges of the pieces of which wearing apparel is made. Laſtly, as the threads of the warp and thoſe of the weft are no longer ſo diſtinct and ſeparated from each other as to leave interſtices between them, the cloth forms a warmer clothing, independently of its having acquired a greater degree of thickneſs. Knit worſted is alſo rendered leſs apt to run, in caſe a ſtitch ſhould drop, by the operation of fulling.

Tentering.—When the milling is finiſhed, the cloth is ſtretched again on the tenter. It is uſual to extend the piece to forty-two yards in length, but not at all in breadth; indeed only one inch of extenſion in each yard is allowed by law. The cloth remains in the open air until it is perfectly dry and ready for the ſucceeding operations of finiſhing, which are only intended to give it a beautiful ſurface, for it already poſſeſſes all the uſeful qualities of cloth.

Dreſſing the Cloth with Teaſels.—This operation is to raiſe up the nap or looſe fibres on the ſurface of the cloth, by ſcratching it over with a ſpecies of thiſtles called teaſels, in order to form a wool on the ſurface, which can be removed by ſhearing. The teaſels are the balls or ears which contain the ſeed of the plant called *dipſacus fullonum*; the ſcales which form the ball project on all ſides, and are terminated with ſharp points, which turn downwards, like hooks, and are very elaſtic. See Teasel.

A number of teaſels are put into a ſmall frame, which is compoſed of a handle eight or ten inches long, having a ſmall ſtick paſſed through it at one end about eight inches long, which is ſplit into two at each end nearly all its length. There is alſo another ſimilar ſtick, which is paſſed through the handle near the middle of its length; the two ſplit ſticks are perpendicular to the ſtem or handle, and parallel to each other. The ſpace between them is filled with teaſels, which are jambed in very faſt between them, and alſo in the clefts of the ſplit ſticks, where they are ſecured by ſtrings extended between the ends of the ſplit ſticks, and twiſted, until they draw the ſticks forcibly together, and bind the teaſels very faſt. This frame filled with teaſels forms a tool, which very much reſembles the curry-comb uſed to clean horſes, and is uſed in a ſimilar manner, to ſcratch over the whole ſurface of the cloth, and draw out all looſe ends of the fibres of the wool, which are not firmly confined by the entanglement of the felting.

The dreſſing is performed by two men, who hold the teaſel-frame by its handle, and work the cloth, when it is hung up in a vertical poſition over two rails fixed to the ceiling; when they have worked over as much ſurface as they can reach, they draw down a freſh portion, which they work in turn, and thus proceed until they have finiſhed the whole piece. The firſt time the cloth is dreſſed it is wetted with water; it is worked three times over in the wet ſtate, by ſtrokes in the direction of the length of the piece, and then it is worked again three times in the other direction; by this means all the fibres are raiſed, and the cloth is prepared for ſhearing.

In the moſt improved manufactories, the dreſſing is performed by the gig or gig-mill. This is a cylinder covered on its ſurface with teaſels, and turned rapidly round whilſt the cloth is drawn over it.

The *Gig-mill* is repreſented in perſpective in *Plate* V. *Woollen Manufacture.* M is the wood frame of the machine; F F is the cylinder or drum, which is compoſed of 12 rails or troughs, filled with teaſels F F, 3, 4, &c. Theſe are faſtened on the circumference of two or three wheels fixed upon a wooden axis 7; the drum is put in motion by a pulley E D at one end of its axis, which receives an endleſs ſtrap, 2, from the drum C, ſituated above the machine. There are two pulleys, E and D, one fixed faſt on the axis, and the other fitted on looſely, with liberty to turn round freely upon it; the ſtrap can be ſhifted to either pulley, and accordingly the machine will be put in motion, or will ſtand ſtill.

The drum C is fixed on one end of an iron ſhaft 1, which is put in motion by a bevelled wheel B, from the larger wheel A, fixed on the great horizontal ſhaft, which proceeds the whole length of the mill. The drum, F F, covered with teaſels, is mounted on bearings ſupported by the frame, and the piece of cloth G is conducted over it, to receive the action of the teaſels; one end of the piece of cloth is wound round a roller J, and the other end of the piece is wound on the roller L; both theſe rollers are put in motion from a bevelled wheel 6, fixed on the extremity of the axis of the drum; this turns a wheel H upon an inclined axis, which has a pinion at each end; one of theſe pinions, 9, turns a bevelled wheel, K, on the end of the axle of the upper

roller L; and the other, 8, turns the wheel I belonging to the lower roller J. By means of this wheel-work both rollers are turned round in the proper direction, to make the upper roller L wind up or draw the cloth, whilst the lower roller unwinds and gives out the cloth. N is a pipe, which conveys water to the machine; it is pierced with a number of holes to throw jets of water on the cloth, and wet it.

As fast as the cloth is taken up by the roller L, it is given out by the other roller J, and is then drawn over the surface of the cylinder, as at G, the teasels of which, as it revolves, act very effectually on the cloth to raise the nap. When the whole piece has passed, and is gathered up on the roller L, the machine is stopped, by shifting the strap 2 to the loose pulley D, then the two rollers L and J are exchanged, and the operation is repeated as before, and so on till the nap is sufficiently raised.

The mode of repeating the action on the cloth by exchanging the rollers is troublesome, and a better mode is to provide the means of disengaging either of the wheels K or I from its respective pinion, making the machine so that only one wheel and pinion can be engaged at once; also to make the motions in such direction that the roller which is engaged shall always wind up the cloth upon itself. Each roller must have a small wheel upon one end of it, as shewn at 10, with a lever and weight 11, to press upon the circumference of the wheel with such force as to occasion a friction, and make the cloth draw tight when it is drawn off the roller. In this way, the cloth can be made to work either backwards or forwards; because that roller which is engaged with the wheel-work will wind up the cloth, and draw it off from the other roller across the drum; but when all the cloth is wound off, that roller which has taken the cloth must be disengaged, and the other put in action, which will make the cloth work back again.

The most improved gig-mills used in Yorkshire have a still better method of moving the cloth. This is by means of a pair of rollers in the place of the upper roller L: they are turned round by a large spur-wheel on the end of the roller, which works in a smaller wheel on the end of the drum; one roller is mounted over the other, like the two rollers of a flatting-mill, and pressed together by screws with sufficient force to draw the cloth between them. The piece of cloth, when brought to the machine, is laid down on a board on the ground before the machine, and one end is passed under the roller J, which is merely to guide it; then it is carried over the drum, as at G, and introduced between the pair of rollers at L, which draw it slowly forwards; from these the cloth turns upwards, and is extended horizontally over two rollers which are suspended from the ceiling. After quitting these rollers, it descends perpendicularly, and is gathered on the ground in folds on a board or bench, close to the place where the piece of cloth was laid before the dressing was begun. In order to make the piece of cloth pass a second time through the machine, or as many times as is required, the two ends of it are sewed together, so that it circulates continually over the drum without any interruption or trouble: it is usually done three or four times.

It is an advantage of this method, that the cloth, in descending from the ceiling, hangs perpendicularly, and with that side which has been dressed opposite to the light, so that the workman who gathers it in folds can examine the progress of the work; and when he judges that the cloth is sufficiently dressed, he cuts the sewing which unites the two ends together, and then the end of the piece comes out of the machine, and the cloth is carried away to give place to another piece.

The drum or cylinder of the gig-mill is composed of a number of shallow troughs, fixed on the circumference of the wheels of the drum, and parallel to its axis: into these troughs, frames filled with teasels, like those we have before described, are fastened in a very simple manner; and the frames are placed so close together, that the trough is wholly filled, and forms a continuous surface of teasels to act upon the cloth when the cylinder revolves. When the hooks of the teasels become filled with flocks or fibres of wool, which they have drawn out from the cloth, they are removed from the cylinder, in order to be cleaned by children, who pick out the flocks with a small steel comb.

The teasels are cultivated very largely in the clothing countries; but it sometimes happens, in particular seasons, that the crops fail, and they are then very dear. This has produced many trials of metallic teeth as substitutes for teasels. Mr. Price of Stroud, in Gloucestershire, has two patents, dated 1807 and 1817, for this object; Mr. Lassalle of Bristol took a patent in 1816, Mr. Williams of Fursley in 1817, and Messrs. Lewis of Brinscomb in 1817. We are not informed if any of these inventions are yet brought into real use in the manufacturing district.

Shearing or Cropping the Cloth.—By the operation of the teasels, the wool is become raised all over the surface of the cloth in a loose fur, which must be removed by shearing before the cloth will be fit for wearing, because the fur would gather dirt and dust, and would wear very unequally.

The shears used for cropping by hand are the same as those used in the common shearing-machine, and are represented at E, E, in *Plate* III. *Woollen Manufacture.* The clothier's shears consist of two very large flat blades of steel, united together by a stem of steel, which is bent into a circular bow, and is sufficiently flexible to allow one of the blades to be moved upon the other, in order to make them cut. Both blades are ground to sharp and straight edges, which apply one to the other, but the blades are not in parallel planes like scissars, for one of the blades is laid quite flat upon the cloth, and the plane of the other blade will then be inclined to the cloth at about an angle of 45 degrees, as is shewn in *Plate* III. The cutting-edge of this inclined blade bears upon the surface of the flat blade, and the spring of the bow is so set, as to press the two edges always in contact. The lines of the edges of the two blades are not parallel to each other, but inclined, so that the edge of the upper blade crosses the edge of the lower blade, and bears upon the flat surface of that blade, at the end nearest to the bow, whilst the other end of the edge of the upper blade is removed over the edge of the lower blade, thus leaving an interval between the two edges, when the shears are open, as is plainly shewn in the figure. In this state, the shears being open, if the lower blade is laid flat upon the surface of the cloth, the nap or wool, which is to be removed by the cropping, will stand up above the edge of the lower blade, in the interval between the two edges; then if the blades be forced together, the edge of the upper blade will pass or cross over that of the lower, and cut away all the wool which projects above the edge of the lower blade. The contact of the cutting-edges begins at the end nearest to the bow, and proceeds regularly to the other, because, as before mentioned, the edges are not parallel to each other. The blades open or return to their former position by the elasticity of the bow, but in order to make the cut they are closed by means of a handle or lever 10, which is fitted or lodged on a round part of the stem of the bow, so as to play thereupon as upon a centre of motion. A double cord is made fast to the lever or handle near to this centre, and

the other end of the cord is faſtened to a block of wood, which is ſcrewed to the flat of the lower blade, and riſes up to a proper height. By depreſſing this handle, the ſhears are cloſed, and make their cut with the greateſt facility, the elaſticity of the bow returning the handle.

The manner of cropping with theſe ſhears is as follows:— The piece of cloth is laid down in folds upon a plank or low bench placed on the ground, and the end is drawn acroſs a table or bench, which is covered with cloth, and ſtuffed with horſe-hair, like a cuſhion. The cloth is ſtretched out flat upon the ſurface of the table, and is retained by hooks and weights. Two workmen are employed to ſhear a piece of cloth; they place the lower blades of their ſhears flat on the ſurface of the cloth, with the line of the edge in the direction of the length of the piece; one of the ſhears is laid on the edge or liſt of the cloth, and the other exactly in the middle of the breadth of the cloth. The bows and ſtems of the ſhears project over the edge of the table, and the workmen place themſelves at that edge. Each man guides the ſhears with his left-hand, and makes the cut with his right. To hold the ſhears by, a ſhort ſtaff is laſhed to the bow of the ſhears, and ſecured by a ſtay to the lower blade; its direction is nearly parallel to the back edge of the upper blade. The workman puts his arm through the bow as far as the elbow-joint, then lays the fore-arm flat againſt the ſtaff, which he graſps with the hand; and in this way he has a great command of the ſhears, leaving the right-hand at liberty to work the handle which cloſes the ſhears. This handle is moved backwards and forwards with great rapidity, to make cuts or clips on the cloth, and between every cut the lower blade is moved a ſmall ſpace on the cloth, to cut in a freſh part.

The art of ſhearing conſiſts in moving the ſhears with great regularity and paralleliſm, ſo that every part of the ſurface ſhall be equally cropped. The cloſeneſs with which the ſhears cut is regulated by weights laid upon the flat of the lower blade; theſe preſs the blade down into the ſoft cuſhion on which the cloth is ſpread, ſo that the fur will ſtand up more above the edge of the blade.

As the two ſhearers advance in their work, their ſhears proceed acroſs the breadth of the piece of cloth, and when the man who began in the middle has worked to the liſt of the cloth, the other who began at the liſt will have worked to the middle, where the firſt began; the whole breadth is now ſhorn, and they remove the ſhears, and draw the piece of cloth forwards acroſs the table, to obtain a freſh ſurface to work upon.

For ſhearing common cloth, it is cut wet the firſt time, then it is dreſſed again with teaſels, dried on the tenter, and cut again in a dry ſtate three times over.

Shearing-Frame.—The moſt common machine uſed in Yorkſhire is only applied to give motion to the ſame kind of ſhears as are uſed for cropping by hand, and is uſually called the ſhearing-frame. At the ſide of the table or cuſhion on which the cloth is ſpread, a long ſtool is placed, having grooves at the edges to guide the wheels of a carriage, to which the ſhears are affixed by their bows. There is a carriage for each pair of ſhears, and they are ſlowly and gradually moved along the ſtool, by a cord which winds upon a roller turned by wheel-work; and at the ſame time, the handles of the ſhears are continually pulled by a cord connected with a ſmall crank, which turns round very rapidly. The direction of the cuts is the lengthways of the piece of cloth, and the two pair of ſhears advance acroſs the breadth of the piece until a whole breadth is cut; the machine is then ſtopped, the ſhears removed, and the piece of cloth ſhifted upon the table. Theſe ſhearing-frames operate very well, but require great care and attention to make the different cuttings join, in order to cut equally over the whole ſurface.

The machine invented by Mr. Harmar of Sheffield was of this deſcription; his firſt patent was in 1787, and another in 1794. At one period his machines were in general uſe, but the preſent ſhearing-frames, although of the ſame kind, are very much ſimplified, and work equally well.

A perpetual Shearing-Machine is repreſented in *Plate* III. *Woollen Manufacture*; it is uſed in the weſt of England, and is beſt adapted for narrow cloths. The ſhears lay croſſwiſe over the piece, which is drawn regularly beneath the ſhears in the direction of its length without any interruptions; hence it is called a perpetual ſhearing-machine.

The ſhears, E E, are the ſame as what we have already deſcribed. Each pair is faſtened acroſs the frame by means of a piece of wood, to which the lower blade of the ſhears are ſcrewed; immediately beneath this blade is the cuſhion to bear the cloth, which paſſes between the blade and the cuſhion. The piece of cloth is wound round the roller C, upon the end of which is a wheel N, and a lever M, which bears up againſt the lower part of this wheel with ſo much friction as to make the cloth ſtrain tight in drawing off from the roller. The cloth firſt paſſes over a rail B, from which it proceeds in an horizontal direction beneath the two pair of ſhears E E, then turns over another rail at the other end of the frame, and deſcends to a roller D, which is turned ſlowly round by the machinery, in order to wind up the cloth.

The machine is put in motion by the endleſs ſtrap round the drum F upon a ſhaft, which proceeds all the length of the mill. The ſtrap turns the pulley G upon the end of the ſmall horizontal ſpindle H: in this ſpindle two cranks are formed at *a* and *b*, which are connected, by wires 7 and 8, with the handles 9 and 10 of the ſhears E, ſo as to give them a continual motion, and make a cut of each pair of ſhears every time the ſpindle H makes a turn. The motion of the machine can be ſtopped by releaſing the lever P, on which the bearing of the ſpindle is ſcrewed: when the lever P is depreſſed, and kept down by the catch, as repreſented in the drawing, the endleſs ſtrap is drawn tight, ſo as to turn the ſpindle; but if the catch is removed, and the lever raiſed up, the ſtrap becomes looſe, and ſlips round upon the pulley without turning it. A ſmall pulley is fixed upon the ſpindle at I, to receive an endleſs ſtrap which paſſes round a larger wheel J. Upon the ſame axis with this are three other pulleys of different diameters, which receive a ſtrap 2, and give motion to three ſimilar pulleys fixed upon a ſpindle 3: the latter ſpindle has a pinion on the end of it, which works a bevelled wheel fixed on the end of the roller D, and thus it is turned ſlowly round. The three pulleys on the ſpindles 3 and J are placed reverſed to each other, that is, the ſmalleſt pulley on one is oppoſite to the largeſt on the other; by this means, the ſame ſtrap 2 may be ſhifted, and will work on any of the three pair of pulleys, but each one will communicate a different degree of movement to the roller D, and conſequently to the cloth, ſo as to draw it quicker or ſlower, and make the ſucceſſive cuts of the ſhears at a greater or leſs diſtance aſunder at pleaſure.

The cuſhions which bear up the cloth againſt the ſhears are moveable on centres of motion, and are capable of being raiſed or lowered. When they are lowered down, the cloth can be readily introduced beneath the lower blades of the ſhears; and when raiſed up, they preſs the cloth up to the ſhears, and the force of this preſſure can be regulated by turning a ſmall handle. In many machines this motion is

applied to the fhears themfelves, inftead of to the cufhion or bed, and is much more convenient.

The perpetual machines anfwer very well for fhearing narrow cloth, when the fhears can cut at once acrofs the whole breadth; and then as the two fhears E work in fucceffion over the fame furface, they crop the cloth twice over in paffing once through the machine. It has been attempted to fhear wide cloths in this machine, by making one pair of fhears take one half the breadth, and the other pair the other half; but it is very difficult to draw a wide piece of cloth fo evenly over the cufhions, as to keep it ftretched to the full breadth without any wrinkles in the lengthways of the piece; and if there are any fuch wrinkles, the cloth will be cut very irregularly. In this particular, the firft machines have the advantage, becaufe the cloth is ftretched over the cufhion by the workman with difcretion, and he makes it tight before the cropping is begun.

There have been many patents for the improvements of fhearing-machines. Mr. Buffington's, in 1804, is for a method of ftretching or extending the cloth breadthways whilft it is in the fhearing-frame. His plan is to attach a narrow web of ftrong cloth to the lifts of the cloth, by fewing or lacing; the outer edge of this web is alfo fewed to a cord or fmall rope, fo that the cloth becomes edged or bordered with ropes. Thefe ropes are conducted through holes or openings in the frame, which will fuffer the cloth and ropes to be moved in the direction of their length; but as the ropes cannot draw fideways out of thefe openings, the cloth may be continually ftretched in its breadth. The openings fhould have rollers to facilitate the motion of the ropes.

Mr. Jofeph Fryer's patent fhearing-machine, dated 1802, acts with three fhearing-blades, one long one, which extends acrofs the breadth of the piece to form the lower or fixed blade, and two other moveable blades of half the length, which are jointed to the long blade at the two ends, and are moveable thereon, fo as to cut in the manner of fciffar-blades. The moveable blades are preffed into contact with the edge of the fixed blade by fprings, and are put in motion by means of two cranks upon an horizontal fpindle, fo that the blades make their ftrokes or cuts alternately. The edge of the lower blade is a ftraight line, but the edges of the moveable blades are convex on the cutting fide, fo as to caufe them to interfect the edge of the lower blade always at the fame angle when they are wide open, as when they are nearly clofed.

The piece of cloth is conducted over proper rollers, and wound up by one, which is turned round by the machine, fo as to draw the piece of cloth from one end to the other with a flow and progreffive motion. The cloth, when it is immediately beneath the edge of the long blade, is bent fuddenly over a narrow ridge of metal, which is parallel with the edge of the lower blade, but fo far diftant as to permit the cloth to pafs between them. This ridge of metal is capable of adjuftment by means of fcrews, and can be placed fo that the nap of the cloth will be fhorn longer or fhorter, as it is required.

In fome cafes, efpecially in finifhing broad-cloths, inftead of drawing the piece from end to end, it may be more convenient to caufe it, or part of it, to move under the fhearing-blades from lift to lift, or from one fide to the other. This will require a machine confiderably larger, though the fame blades will fuffice; or it is found equally convenient to caufe the blades, at the time they are cutting, to move over the cloth in any direction, but more efpecially from lift to lift.

Mr. Fryer alfo contemplated the finifhing of the cloth by the fame machine which performed the fhearing. Thus after the cloth has undergone the operation of fhearing or cropping, in its paffage down to the cylinder on which it is wound up, it is expofed to a current of fteam thrown out from a horizontal tube at a number of fmall apertures, fo as to give foftnefs and pliability to the cloth; a brufhing cylinder is next made to move againft it, by which the remaining wool or fur is laid in one direction. It then paffes between two polifhed metal cylinders, which are made hollow, and kept hot by the admiffion of fteam or otherwife. Thefe occafion a great preffure on the cloth, and diffipate all the water imbibed from the fteam.

Rotatory Shearing-Machine.—A very complete machine for cropping cloth of any breadth was invented by Mr. Price, of Stroud, in Gloucefterfhire, and for which he obtained a patent in 1815. This machine fhears or crops the cloth acrofs the breadth, beginning at one end of the piece, and continuing regularly to the other. For this purpofe, the cloth is conducted through the machine by the motion of rollers, and is drawn over a bed or fupport which lies beneath the ftationary or fixed blade of the fhears or croppers, (which anfwers to what is called the ledger-blade in the common fhears,) fo that the cloth paffes between the bed and the ftationary blade.

The moving blades of the fhears are fixed on the circumference of a cylinder fituated above the fixed blade, with its axis exactly parallel thereto, and capable of revolving by the power of machinery, fo that the edges of the moving blades will be carried againft and paffed over the edge of the fixed blade, in order to cut away all the wool of the cloth which rifes above the edge of the fixed blade. Several fuch moving blades are fixed upon the fame cylinder, to act in fucceffion againft the fixed blade; and thefe moving blades are placed obliquely to the axis of the cylinder, or in fuch a manner as to form portions of fpirals; but as all parts of the cutting edges are equidiftant from the axis of the cylinder, it is manifeft, that in the revolution of the cylinder, every part of each fpiral edge is brought in fucceffion into contact with the fixed blade, fo that in its revolution it crops off all the wool, which by the progreffive motion of the cloth over its bed is raifed up againft the fixed edge. The edges of the moving blades are placed at fuch a degree of obliquity to the axis of the cylinder, that at the fame inftant the end of one ceafes to cut againft the edge of the fixed blade, the following revolving blade will begin its action at the other end of the cylinder; therefore, by the time that any one of the revolving edges has paffed over and made its cut againft the whole length of the fixed blade, and is ready to quit it, the fucceeding revolving edge is brought into action, and when this has paffed, the next in fucceffion begins, fo as to keep up a continued action.

The cloth is ftretched in width by a contrivance which he calls ftretching-bands, to prevent it getting into folds or wrinkles, which would be injured by the fhears, or make irregularities in the fhearing. Thefe ftretching-bands are endlefs ftraps or bands, each of which is extended over two wheels. The bands have fharp pins projecting from them to prick into the lifts at the edges of the cloth, and the bands being fo fituated that one of them lies exactly beneath each lift, they will be caufed to circulate round their refpective wheels by the motion of the cloth. The ftretching of the cloth is effected by the pofition of the wheels on which the bands circulate, the direction of the bands being flightly oblique to the lengthways of the cloth. The endlefs ftraps are fo fitted into grooves or troughs, that they are firmly retained to move ftraight forwards in their oblique direction; and the direction of the obliquity is fuch, that the

bands are neareſt together at that end where their pins take hold of the liſts of the cloth; but as the bands move forwards with the cloth, they recede from each other, and extend the cloth in breadth in conſequence of their obliquity, which may be increaſed or diminiſhed as is found neceſſary. The actual width between the two bands can alſo be regulated according to the width of the piece of cloth.

It is not uſual to crop the liſts of the cloth, and indeed as the liſts are uſually of thicker ſubſtance than the other parts of the cloth, they would bear up the fixed blade too high from the cloth to cut the nap quite cloſe.

For this reaſon, the bed or ſupport on which the cloth is cut is ſo conſtructed, that it can be adapted in length to the breadth of the piece of cloth between the liſts, in order that the cloth only may be ſupported or borne up to the edge of the fixed blade; whilſt the liſts, being depreſſed or borne down below the level of the bed, (by thin ſlips of metal called guards,) will eſcape the action of cropping, and thereby remain with the long wool upon their ſurfaces. The bed by which the cloth is borne whilſt it is cut is only a narrow ridge of metal, over which it paſſes, ſo as to be bent with a ſudden curvature, and in this way, the nap can be cut more cloſe and even than upon a flat bed or ſoft cuſhion. The operation of cutting is facilitated by a row of pieces of metal ſcrewed to a ſtrong bar, to form a ſtraight edge, very ſimilar to the cutting edge of the fixed blade, but thin and elaſtic; this edge is placed cloſe to the elevated ridge of the bed, and preſſes the cloth gently down upon the bed immediately before it comes to the edge of the fixed blade, againſt which the nap is to be cut off; this elaſtic edge being placed on one ſide of the ridge, and the cutting edge of the lower blade on the other ſide, the cloth is only expoſed for a very narrow ſpace juſt where it comes to the cutting edge. By this means, the cloth can with ſafety be brought nearer to a level with the upper ſurface of the fixed blade, ſo as to ſhear it cloſer than could otherwiſe be done without endangering the cloth.

The ends of the ridge part of the bed are compoſed of a number of narrow plates of metal, accurately fitted together, and placed ſide by ſide in a mortiſe made in the end of the ſolid bed; their upper ends project out of the mortiſe ſo as to line with the elevated ridge, and form a continuation thereof; but there is a ſliding piece in the bottom of the mortiſe on which they all bear, and the point of it is of a wedge form. By removing this wedge, any number of the moveable pieces may be let down, ſo as to diminiſh the length of the elevated part of the bed at pleaſure, according to the breadth of the cloth. The whole of this machine is very well contrived to effect the deſired object; it will be found fully deſcribed with drawings in the Repertory of Arts, vol. xxix. p. 65.

Frizing is an operation ſometimes uſed in the finiſhing of woollen cloth: it conſiſts in rolling up and entangling the fibres, which form the nap on the ſurface of the cloth into ſmall knots or burs, which cover near the whole ſurface, ſo that the cloth appears covered with ſmall grains, which almoſt touch each other.

This operation is of no utility to the cloth, and it is difficult to ſay for what reaſon it was ever practiſed at all. The French firſt introduced it, and it was ſo much the faſhion many years ago, that no other cloth was thought comparable in beauty. At preſent it is but little uſed, except for foreign markets, where our cloth meets the French cloth, which is ſtill prepared in this manner, but generally on the back-ſide of the cloth only.

The frizing is done by a ſimple machine, in which the cloth is drawn acroſs a narrow table by means of rollers, to give it a very ſlow progreſſive motion. The table is covered with a coarſe ſtrong cloth, and over the table is placed a heavy plank of wood, of the ſame ſize as the table. The lower ſide of this plank, which bears upon the cloth, is covered with an artificial ſtone, compoſed of coarſe ſand, which is ſtuck together into a ſolid maſs by glue or other cement, and a ſmall but rapid reciprocating motion is given to the plank by means of two cranks of very ſmall radius. Theſe cranks are formed at the tops of two vertical ſpindles, the upper ends of which are fitted in ſockets at the ends of the fixed table, and the ends which project up a few inches above the ſurface of the table are received into ſockets formed in each end of the moveable plank. The projecting parts of the ſpindles are not in ſtraight lines with thoſe parts which are fitted in the fixed collars at the ends of the table, but are ſlightly cranked; hence, if the ſpindles are turned round, they muſt communicate motion to the plank, and ſlide it over the cloth backwards and forwards; or rather they move it with a circular motion, cauſing every point and grain of ſand cemented to the plank to deſcribe a ſmall circle upon the cloth. It is this action which gathers together the fibres of the nap, and entangles them into knots or grains, as before mentioned.

To put the two ſpindles in motion, each one has a trundle or lantern fixed on the middle part of it, and the lower end is received in a ſtationary ſocket. Theſe lanterns are turned round by the teeth of two face-wheels, fixed upon an horizontal axis, which lies beneath the machine. By this means, both the ſpindles and cranks are turned round at the ſame time, and with a very rapid motion. The rollers which draw the cloth forwards are turned round ſlowly by a communication of wheel-work, and draw the piece of cloth through the machine, that is, acroſs the frizing-table, ſo that every part is in turn ſubjected to the action of the ſand cemented to the plank. The nap muſt be left long for that cloth which is intended to be frized, and the operation is repeated twice or three times. See ſome further particulars in our article Frizing, vol. xv.

Bruſhing.—After being ſhorn for the laſt time, the cloth is bruſhed all over, to remove the looſe cuttings. This operation is now commonly performed by a machine which has two horizontal drums, or cylinders, covered with hair-bruſhes on the circumference. The piece of cloth is conducted over a ſyſtem of rollers to extend it and draw it ſlowly forwards: it is conducted over one of the bruſhing-cylinders, and under the other; and as they are kept in rapid motion by the machine, they bruſh over both ſides of the cloth at the ſame time, and lay all the fibres one way.

Preſſing.—This is the laſt finiſh to the cloth, and gives it a ſmooth and even ſurface. The piece of cloth is folded backwards and forwards at every yard, ſo as to form a pack on the board of a ſcrew-preſs; and between every fold ſheets of glazed paper are placed, ſo that no part of the ſurfaces of the cloth can come in contact; alſo at every twenty yards three hot iron plates are put in between the folds, the plates being laid ſide by ſide, ſo that they occupy the whole ſurface of the folds; and thin iron plates, which are not heated, are alſo put above and below the hot plates to moderate the heat. When the pack of cloth is properly folded, and the preſs contains a proper quantity, the ſcrew is forced down to give a very ſevere preſſure to the pack. The cloth remains in the preſs until the plates are quite cold; it is then taken out and folded again, ſo that the creaſes of the former folds will come oppoſite to the ſurfaces of the paper, in order to be preſſed with other hot plates.

The heat tends to ſoften the fibres of the wool, and the

preſſure againſt the glazed paper, whilſt they are ſo ſoftened, lays all the fibres flat and ſmooth, ſo that the cloth has a very gloſſy appearance, and feels ſmooth, like ſatin; but this high finiſh to the cloth is very objectionable, becauſe the ſlighteſt ſhower of rain will take it away, and when the drops of rain only wet it in parts, the cloth will become ſpotted and disfigured. For this reaſon, in preſſing ſuperfine cloth, the plates are very ſlightly warmed, and the cloth has but little gloſs given to it. The glazed paper is a thick kind of cartridge, which is prepared by glazing or rubbing it very forcibly with a flint, as it lies upon a hard metal table. This operation is done by a water-mill.

For coarſer cloths, ſome manufacturers gloſs them with a large hot iron: it is a hollow box, into which a red-hot heater is introduced. The cloth is ſpread out upon a large flat table, and extended by hooks. The iron box is ſuſpended by a tackle from the ceiling, ſo that it can be hoiſted over to the middle of the table, and then two men work it backwards and forwards over the whole ſurface of the cloth, by means of two long poles or handles, which are jointed to it at one end.

The cloth is now finiſhed, and is packed up in bales of twenty or twenty-five pieces, in order to be tranſported. The bale is firſt incloſed in paper, and then in canvas, and cloſely compreſſed by the ſcrew-preſs. Some manufacturers uſe the hydroſtatic preſſes for this purpoſe.

In conſidering the proceſſes of the woollen manufacture, as they were practiſed forty or fifty years ago, and comparing them with the preſent practices, we find great changes and improvements, but they are by no means carried to ſo great an extent as in the cotton manufacture. This is owing in a great degree to the circumſtance that the manufacture of woollen cloth was rendered very perfect, as far as the goodneſs and beauty of the cloth was concerned, long before the improved ſyſtem was begun; and there were great numbers of experienced and able workmen trained up for each proceſs, who by habit and dexterity performed their work as well as it could be done by machinery. The reduction of labour, or the ſubſtitution of ordinary hands for experienced workmen, was in this caſe all that machinery of the moſt perfect kind could effect; both theſe were advantages to the public and the manufacturer, but were ſo directly oppoſite to the inclination and intereſt of the able workmen, that we find they have made greater and more effectual oppoſition to the introduction of improvements in the woollen than in any other of our great manufactures.

At various periods attempts have been made by the workmen to ſuppreſs machinery, and many mills have been deſtroyed. In July 1802, conſiderable riots took place in Wiltſhire and Somerſetſhire, in conſequence of an attempt to ſet up the machines called gig-mills. It was contended that this was the ſame machine which was prohibited by an ancient ſtatute of Edward VI. The diſputes ran ſo high, that the attention of parliament was called to the ſubject of the laws then exiſting for the regulation of the woollen manufacture, and a committee was appointed to inveſtigate the policy of encouraging or regulating machinery. In conſequence, all the prohibitions of machinery were ſuſpended. The report of this committee contains the following remarks, ſome of which are applicable to other manufactures as well as the woollen.

The introduction of the gig-mill and other machines was oppoſed from an idea that it would throw a conſiderable number of hands out of work; and it was contended, that it was highly injurious to the quality and texture of the cloth. With reſpect to the actual effects of the gig-mill and ſhearing-frame on the cloth, the committee report that deciſive evidence has been adduced before them by merchants and manufacturers of the greateſt credit and experience, to prove that theſe machines, eſpecially the gig-mill, when carefully employed, finiſh the cloth in the moſt perfect manner, and that manufacturers reſiding in parts of the country where the gig-mill is not uſed, frequently ſend their cloths to a diſtance to be dreſſed by it.

It alſo appeared in evidence, that alarms ſimilar to the preſent had exiſted among workmen at the introduction of ſeveral of the machines which are now in general uſe. Such alarms have gradually ſubſided as prejudice died away; and the machines are now fully eſtabliſhed, without, as it appears, impairing the comforts or leſſening the numbers of workmen. The committee remark with much ſatisfaction, that in many inſtances in which it was apprehended that the introduction of particular machines would throw ſuch a number of people out of employment as to occaſion great diſtreſs, the reſult has been very different; for beſides the occupations which the attendance on ſuch machines has given riſe to, a freſh demand for labour to an immenſe extent has ariſen out of the increaſed ſale of the article, in conſequence of the cheapneſs and ſuperior quality of the manufacture.

They approve the ſyſtem of patents, by which the inventor of any new machine ſecures to himſelf the excluſive benefits of his diſcovery for fourteen years; and only, at the end of that term, they are thrown open to the public; this provides in moſt caſes againſt the too ſudden and general eſtabliſhment of any invention, by which a number of workmen might at once be thrown out of employment.

They next obſerve, that if the principles on which the uſe of theſe particular machines is objected to were once admitted, it would be impoſſible to define the limits or to foreſee the extent of their applications. If the parliament had acted on ſuch principles fifty years ago, the woollen manufacture could never have attained to near its preſent extent. The rapid and prodigious increaſe of late years in all the manufactures and commerce of this country is univerſally known, as well as the effects of that increaſe on our revenue and national ſtrength. In conſidering the immediate cauſes of that augmentation, it appears to the committee, that it is principally to be aſcribed, under the favour of Providence, to the general ſpirit of enterprize and induſtry among a free and enlightened people, left to the unreſtrained exerciſe of their talents in the employment of a vaſt capital, puſhing to the utmoſt the principle of the diviſion of labour, calling in all the reſources of ſcientific reſearch and mechanical ingenuity, and, finally, availing themſelves of all the benefits to be derived from viſiting foreign countries, not only for forming new and confirming old commercial connections, but for obtaining a perſonal knowledge of the wants, the taſte, the habits, the diſcoveries and improvements, the productions and fabrics, of other civilized nations. Thus bringing home facts and ſuggeſtions, perfecting our exiſting manufactures, and adding new ones to our domeſtic ſtock; opening, at the ſame time, new markets for the product of our manufacturing and commercial induſtry, and qualifying ourſelves for ſupplying them.

The committee declare it to be their opinion, that by theſe means alone, and above all by the effect of machinery in improving the quality and cheapening the fabrication of our various articles of export, notwithſtanding a continually accumulating weight of taxes, and with all the neceſſaries and comforts of life gradually increaſing in price, (the effects of which on the wages of labour could not but be very conſiderable,) our commerce and manufactures have alſo been increaſing in ſuch a degree as to ſurpaſs the moſt ſanguine calculations of the ableſt political writers who have ſpecu-

lated on the improvements of a future age. The exports of woollen goods at the time of this report, (1807,) amounted to fix millions of pounds official, or nine millions of real value.

It appeared alfo to be an important confideration, of which we fhould never lofe fight, that we are at this day furrounded by powerful and civilized nations, who are intent on cultivating their manufactures and pufhing their commerce; and who are more eager to become our competitors in trade, from having witneffed the aftonifhing effect of our commercial profperity. The attempts which have been made to carry our machines and implements over to foreign countries, and to tempt our artifans to fettle in thofe countries, evince the importance of machinery, under the directions of men of approved fkill, in conftructing and ufing them. It is needlefs to remark how much thefe attempts would be favoured by our throwing any obftructions in the way of enterprize and ingenuity, and the free application of capital in this country; for any machines which fhould be prohibited here would infallibly find their way into foreign nations in a very fhort time.

Among the attempts to improve the woollen manufacture, we muft not omit to notice the invention of Mr. Jofeph Booth, for fabricating woollen cloth without fpinning or weaving. This was effected by felting wool into a web by the aid of machinery, which operated mechanically upon a tiffue of carded wool, to entangle and interlace the fabrics together. The inventor took a patent for this in 1793 or 1794, but before the time for the enrolment of the fpecification of his procefs, he obtained an act of parliament, the preamble of which ftates, that on account of the great importance of the art, and the danger of its being carried abroad to the injury of the ftaple manufacture of the kingdom, parliament had determined to keep the fpecification fealed; hence we are not able to give the details of this machinery.

We find thefe expectations have not been realized; for, although the procefs has been repeatedly tried on a large fcale and in the moft complete manner, it has been abandoned. Three large mills were eftablifhed at Taunton and near Salifbury, by experienced woollen manufacturers of the weft of England; another mill was converted to the purpofe at Lewifham, in Kent; and the laft mill was erected at Merton, in Surrey, the property of James Perry, efq. We learn from this gentleman, that he was able to manufacture cloth of a fine furface, and of a very even and regular fubftance, but it was rather deficient in ftrength, for want of the threads which form the fubftance of common cloth; and in refpect to wear it was lefs durable than common cloth, as it did not long withftand brufhing; otherwife the expence of the procefs, which was not one-fourth of the common procefs, would have brought it into general wear.

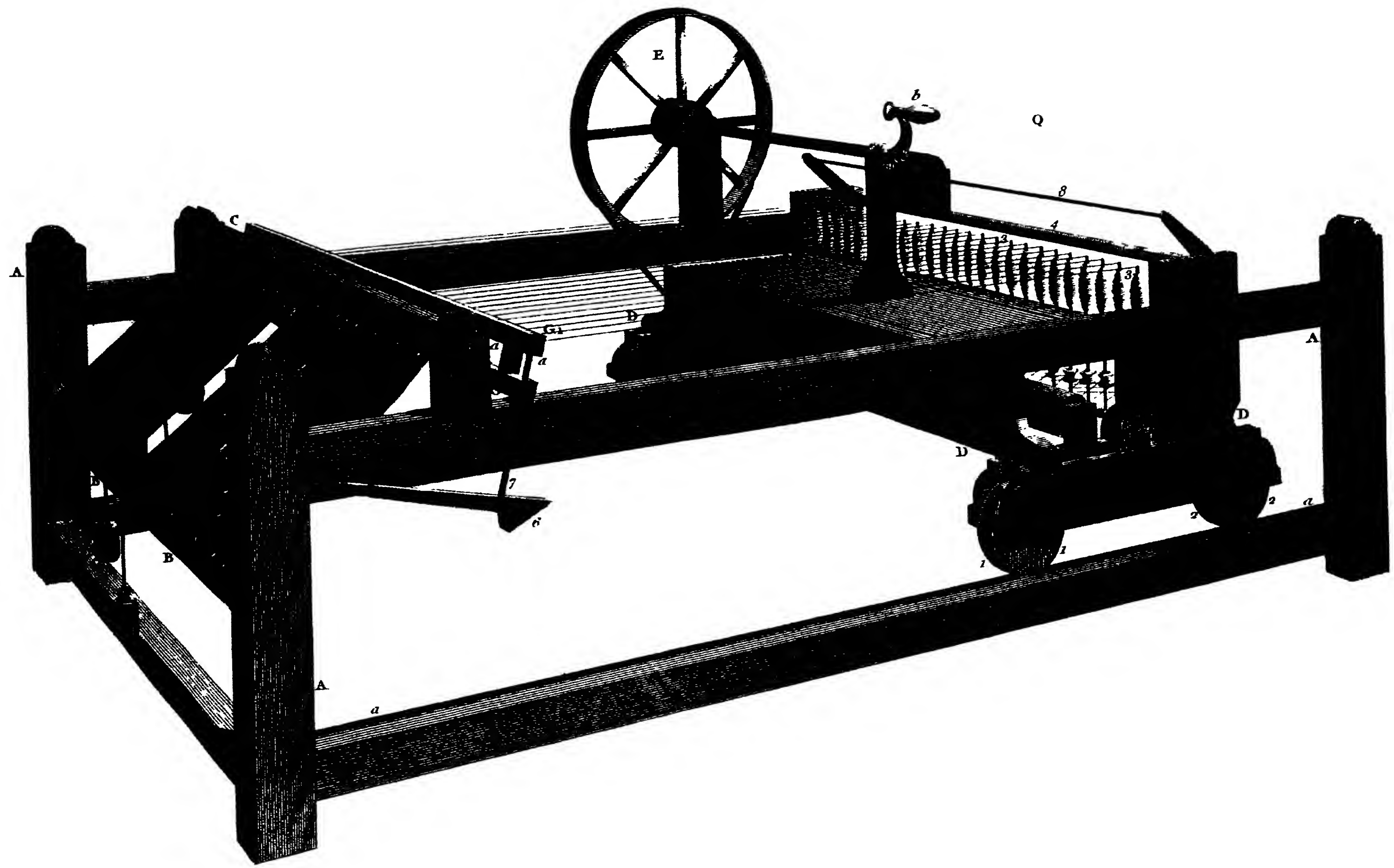
There has been a great number of other projects and patents for the improvement of different branches of the woollen manufacture; but as we have already noticed moft of thofe which have come into ufe, we fhall not enumerate any more of the unfuccefsful attempts.

The machinery for manufacturing long combing-wool is defcribed in the article WORSTED.

WOOLLEN MANUFACTURE.

PLATE I.

SLUBBING MACHINE OR BILLY.



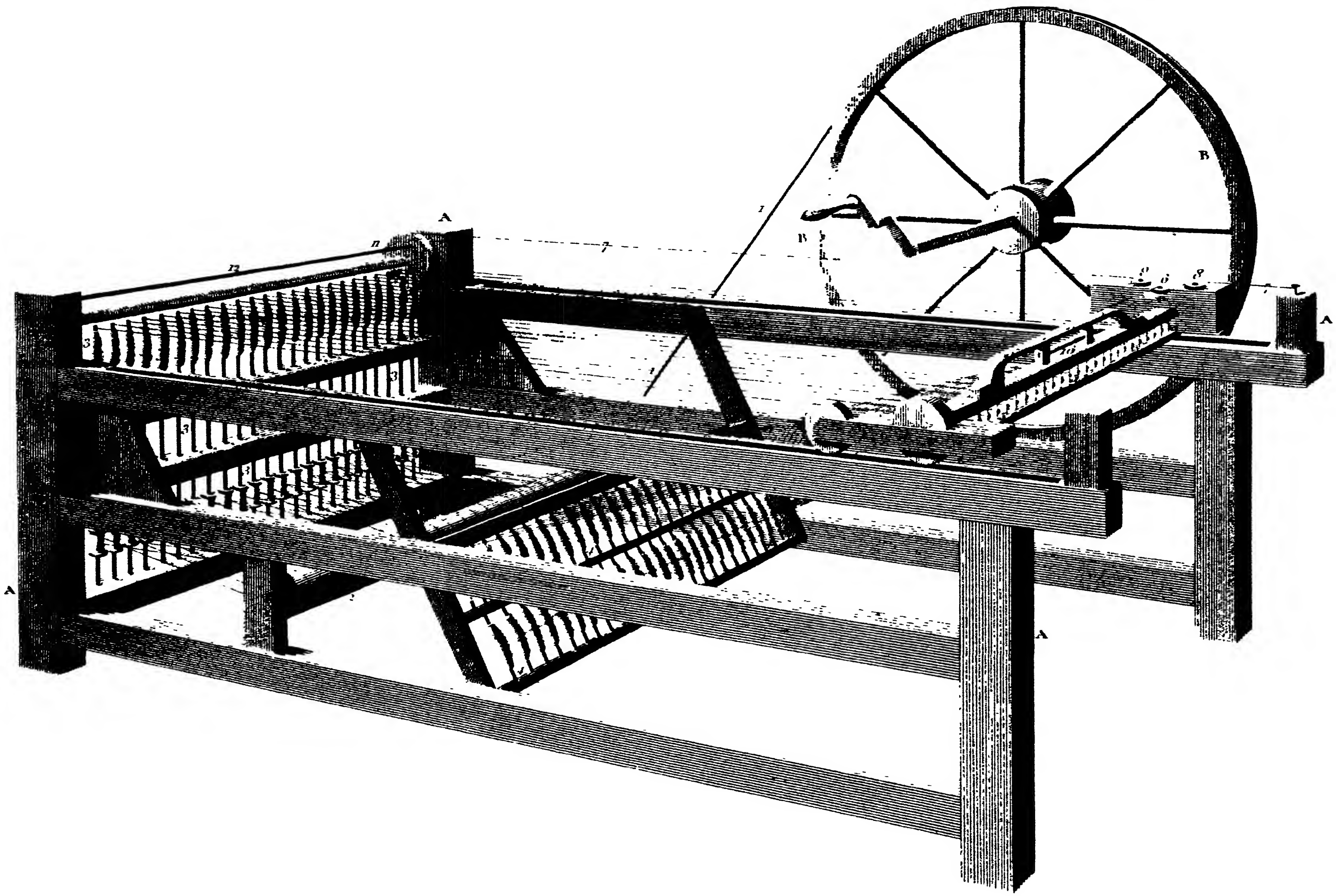
J. Herbert delin.

Published as the Act directs ... by Longman Hurst Rees & Orme Paternoster Row

Engraved by Wilson Lowry

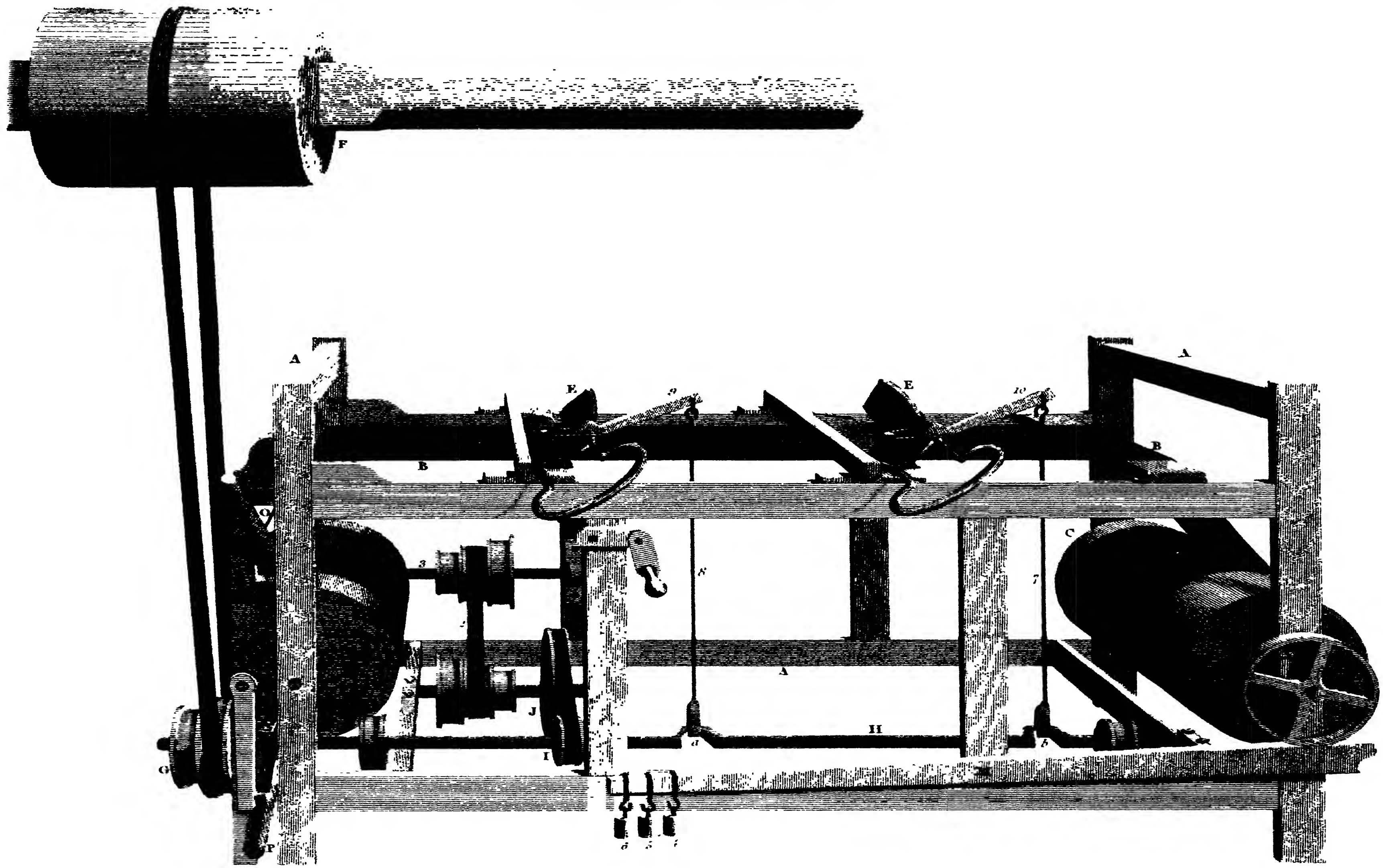
OOLLEN MANUFACTURE

SPINNING JENNY.



WOOLLEN MANUFACTURE.

SHEARING MACHINE.

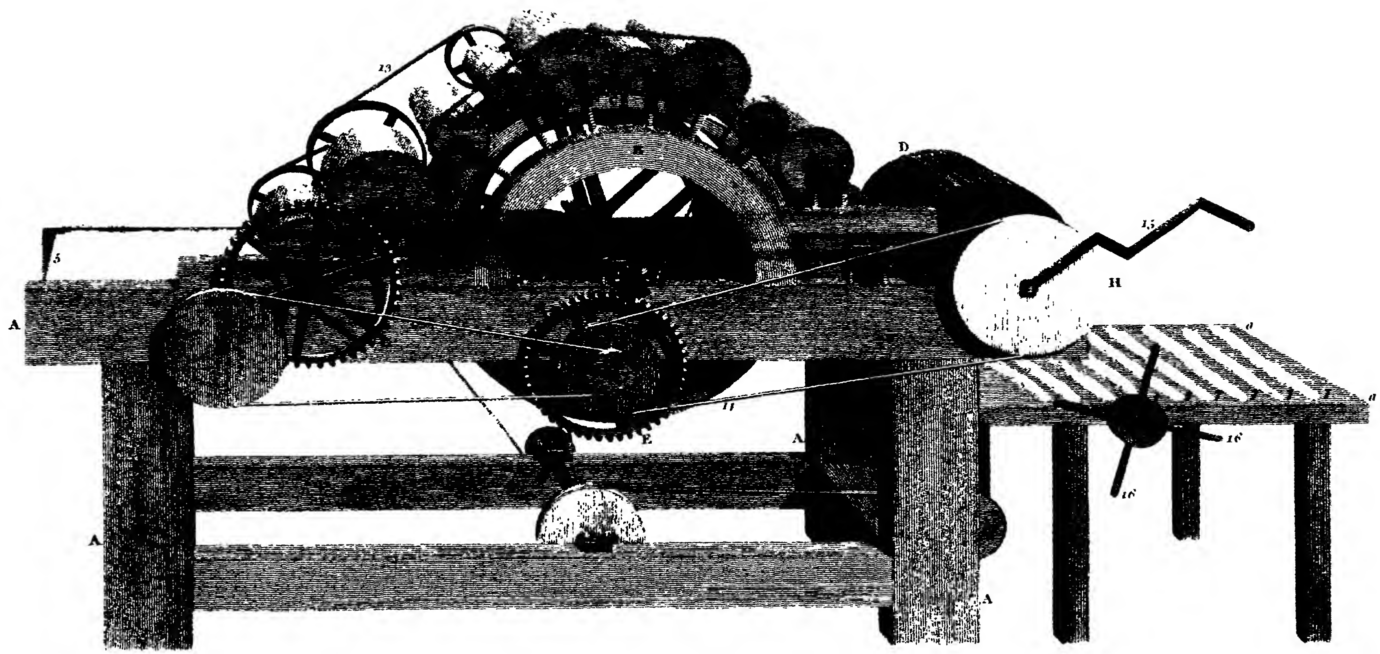


Published as the Act directs 1811 by Longman Hurst Rees Orme & Brown Paternoster Row

PLATE

WOOLLEN MANUFACTURE.

CARDING ENGINE.

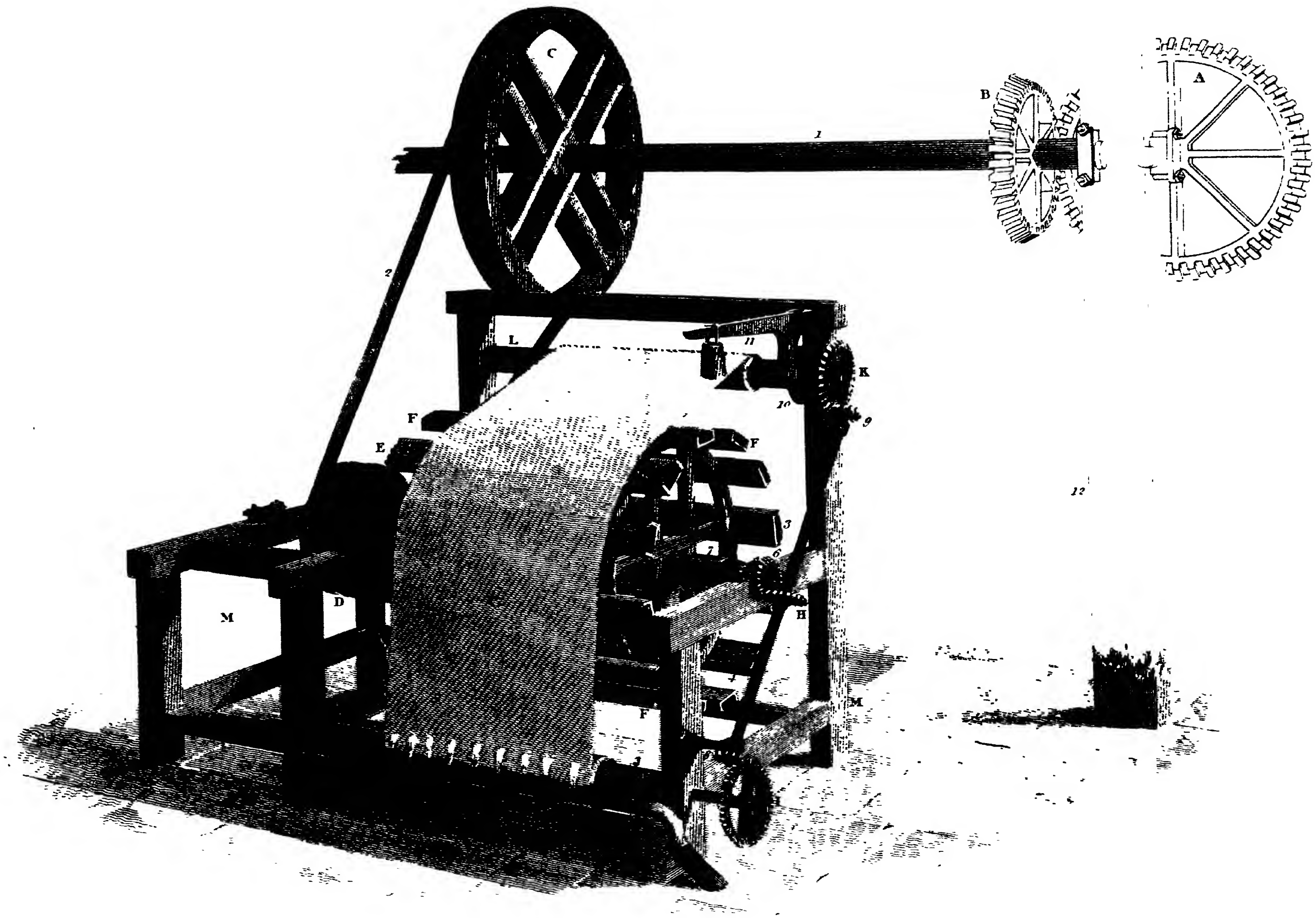


J. D Herbert delin.

Published as the Act directs, 1809 by Longman, Hurst, Rees & Orme, Paternoster Row.

Engraved by Wilson Lowry.

WOOLLEN MANUFACTURE



Published as the Act directs 1815 by Longman, Hurst Rees Orme & Brown Paternoster Row.

Lowry sculp.

Worsted

WORSTED, and WORSTED *Manufacture*. The term worfted is applied to yarn, and manufactured goods made of combed wool. Worfted is properly a branch of the *Woollen Manufacture*, to which article we refer our readers; but the latter term, ftrictly fpeaking, is applied only to yarn, or pieces made entirely or in part of carded wool. The characteriftic diftinction between combing-wool and fhort or clothing-wool has been already ftated under the article WOOL. (See WOOL and WOOLLEN *Manufacture*.) Worfted goods were made in England as early as the time of Edward II. In the account of exports in the following reign, already given in the article WOOLLEN *Manufacture*, the number of pieces of worfted goods exported is nearly double that of woollen cloths. According to Camden, the name is derived from Worfted, a town in Norfolk, where worfted ftuffs were firft made. According to Dr. Parry, in his "Effay on the Merino Breed of Sheep," worfteds were called by the Flemings '*Oftades*,' and as the manufacture was in their hands long before it was introduced into England, it is probable that our appellation is a corruption of their's. Oftade was long ago a common furname in Flanders, and was perhaps that of fome perfon famous for this particular branch of the woollen trade, which afterwards was appropriated to an eftablifhment of fimilar manufacturers in Norfolk.

Worfted yarn is made of long or combing-wool, in which the fibres are all laid even parallel with each other by the wool-comb. It may be claffed into two great divifions, the foft and the hard worfted yarn. The foft yarn is made of the fhorter kinds of combing-wool, the forting of which has been already defcribed under the article WOOL. The fhort and long combing-wools are both prepared for fpinning by the comb in the fame manner, except that for fome kinds of fine hard yarn made from the latter, the wool is combed, and afterwards fpun nearly without oil. This is the cafe with the yarn for bombazines. The foft yarn for hofiery receives but little twift in the fpinning, and two, three, or more threads are afterwards twined together on what is called a doubling-mill, to make a thread of requifite ftrength and thicknefs to be woven on the ftocking-frame. See STOCKING-*Frame*.

Knitting-yarn is twined much harder than yarn for the frame. For mixed coloured ſtockings, part of the wool is dyed and mixed with the white in the proceſs of combing. The principal ſeats of the worſted hoſiery manufacture in England were Nottingham and Leiceſter; but of late years the worſted hoſiery has declined at the former place, the trade there being principally confined to ſilk and cotton articles. Formerly hoſiery compriſed a variety of worſted articles, particularly caps, which were generally worn in England before the introduction of hats.

At Aberdeen, in Scotland, there is a conſiderable manufacture of hoſiery, the wool being principally ſupplied from London. Worſted ſtockings, and lamb's-wool hoſiery, to the amount of from fifty to ſeventy thouſand pounds, are ſaid to have been annually exported from Aberdeen to Holland. Of the number of hands employed in worſted hoſiery in England, or the annual value of the goods made, we have no correct account. Perhaps ſome eſtimate may be formed from the amount of exports of woollen hoſiery given under the head *Woollen Manufacture*, in the table of exports, in which it will be ſeen, that in the year 1816 the worſted hoſiery exported amounted to one hundred and fifty-one thouſand and ſixty pounds. This, we believe, includes the hoſiery made of woollen yarn, or what is generally called lamb's-wool yarn, an article which, ſince the beginning of the preſent century, has been greatly increaſing in demand. Soft worſted yarn for hoſiery, during the laſt twenty years, has been principally ſpun and doubled by machines in large worſted-mills. Previouſly to that time, worſted-making by hand-ſpinning was a diſtinct trade from hoſiery. The worſted-maker bought his different ſorts of combing-wool from the wool-ſtapler, combed and ſpun it, and ſold the yarn to the hoſier. Since then, the hoſiers have been principally ſupplied with worſted yarn from large mills eſtabliſhed in Leiceſterſhire, Nottinghamſhire, and Warwickſhire. Of late, however, many of the hoſiers are manufacturing their own yarn on machines or mules turned by the hand, or in ſmall mills turned by horſes or water.

The combing-wools of Kent are better ſuited for hoſiery worſted yarn than any other in England, particularly for machine-ſpinning. This excellence is derived partly from the ſoftneſs as well as ſoundneſs of the wool; but particularly from the ſtaple being nearly of one uniform thickneſs from the bottom to the top. See Wool.

Picardy and Normandy were the principal ſeats of the worſted hoſiery in France. Under the article Woollen *Manufacture*, it will be ſeen that 1,250,000 pounds weight of wool were conſumed annually in the manufacture of hoſiery in Picardy before the French revolution.

The ſtocking-frame was invented by William Lee, M.A. of Cambridge, in 1589, and was afterwards introduced into France. This invention took place in England only 28 years after the knitting of hoſiery yarn on needles had been introduced from Spain. See Stocking-*Frame*.

Hard worſted yarn for worſted ſtuffs or pieces is ſpun much ſmaller, and twiſted much harder, than the ſoft worſted yarn for hoſiery. In all the ſtouter kinds of worſted goods, the long or heavy combing-wool is uſed. (See Wool.) Under the article Woollen *Manufacture* we have noticed the introduction of the worſted trade into England, and various places where it was firſt eſtabliſhed. Norwich and ſome of the towns in Norfolk and Suffolk appear to have been the firſt where any conſiderable quantity of worſted pieces or ſtuffs were made. The names which the different kinds of worſted pieces have received are very numerous, being often derived from the manufacturer who introduced a ſlight change either in the mode of weaving or finiſhing the goods. Theſe names ſoon became obſolete, being ſupplanted by other kinds of worſted goods, ſo that we do not know at preſent to what particular kind of pieces ſome of them were formerly applied; the eſſential difference conſiſting in their being woven plain, twilled, or figured, or made with a warp of ſingle or doubled yarn, and woven ſtouter or more ſlightly, or of greater or leſs width, and whether they were glazed or not in the finiſhing.

The moſt important diſtinction between worſted pieces and woollen cloth conſiſts in the former not being milled or raiſed, ſo as to cover the ſurface with a pile, but the thread is left bare. To take off the looſe hairs which riſe from the ſurface, the worſted pieces are paſſed over a red-hot cylinder, in the ſame manner as many kinds of cotton (ſee Cotton *Manufacture*): this proceſs is called *ſinging*. For ſome particular purpoſes, a ſlight degree of milling has recently been attempted to be given to worſted pieces in the fulling-mill. The glazing communicated to ſome kinds of worſted goods is given by preſſing them between ſheets of ſtiff glazed preſs-paper and heated iron plates, which are compreſſed in a ſtrong preſſing-frame. For the weaving of figured pieces, ſee Weaving, and Draught *of Looms*.

Some kinds of very fine worſted goods are made with a warp of mohair or ſilk, as ſilk camlets and bombazines. The latter goods, with a ſilk warp and wefted with hard worſted yarn of the fineſt kind, are manufactured at Norwich. The term bombazine appears to be derived from bombycina, a kind of ſilk dreſs uſed by the Romans, and ſaid to come from Aſſyria. It is generally underſtood to have been made from the threads of an inſect called the bombyx. Bombycina is ſometimes confounded by commentators with byſſinum and ſericum. Byſſinum appears to have been a very fine kind of linen or lace; ſericum unqueſtionably means ſilken ſtuff, ſo called from the Seres, the nation whence it was procured. Probably bombycina was a coarſer kind of ſilk. In the middle ages, the word bombycina was applied to cotton. Macpherſon's Annals of Commerce. See Byssus.

Bombazines are woven with a twill, and have, as before ſtated, a warp of ſilk and a weft of fine worſted yarn. The Dutch refugees, who fled from the perſecution of the duke of Alva, introduced the manufacture of this article into Norwich in the year 1675, when the Dutch elders, according to Blomefield, preſented bombazines in court at Norwich. (Blomefield's Hiſt. of Norfolk, vol. ii. p. 205.) Worſted goods were made in Norwich as early as the reign of Edward II. This appears from a patent granted to John Peacock, for the meaſuring every piece of worſted made in the city of Norwich or county of Norfolk. Norwich has continued from that time one of the principal ſeats of the worſted and ſtuff trade. The ſale of ſtuffs made in Norwich only, in the reign of Henry VIII., amounted to 100,000*l.* annually, beſides worſted ſtockings, which were computed at 60,000*l.*

Norwich is at this day the only part of England where any conſiderable number of the very fineſt ſtuffs and bombazines are made. The manufacture of the coarſer kinds of worſteds, except camlets, has been transferred in a great meaſure into Yorkſhire. The period preceding the American revolution, from the year 1743 to 1763, may perhaps be regarded as the moſt flouriſhing era of the worſted manufactures of Norwich. According to the account of Arthur Young in 1771, the manufactures of this place had increaſed four-fold in the preceding 70 years. The number of looms was then eſtimated at 12,000, and each loom was ſuppoſed to employ ſix perſons in preparing and finiſhing

the material; and the total annual value of the goods was estimated at above 1,200,000*l*. Of these goods the estimate then was,

		£
The export to Rotterdam	- -	480,000
——— to London	- -	550,000
——— to various places	- -	200,000
Total value	-	1,230,000

The number of persons employed being from seventy to eighty thousand.

Since the time to which Arthur Young refers, the manufacturers of Norwich have engaged extensively in the trade of silk shawls and other articles, in which no worsted whatever is used. Still, however, the worsted manufactures of Norwich may be considered as in a flourishing state. The number of looms employed in worsted at the present time (1818) may be estimated at 10,000; half of which weave camlets, calimancoes, and other stuffs; and the other half bombazines, narrow and broad. The former are chiefly for home consumption, the latter for the Spanish market. The East India company take a considerable quantity of the fine camlets manufactured at Norwich.

By far the greatest part of the worsted yarn employed at Norwich is supplied by machine-spinning, from the worsted-mills in Yorkshire, Lancashire, and Durham. But some yarn still continues to be spun in the old manner, by the running-wheel, in Suffolk, Essex, Hertfordshire, and Cambridgeshire. In Norfolk alone, the use of the distaff still remains. This instrument is the most ancient of which we have any notice, either in sacred history, or the fabulous traditions of Grecian mythology handed down to us by Homer and Hesiod. It is at present vulgarly called the rock. In using it, the thread is drawn out from the end of the sliver of combed wool. The motion is communicated to a rough kind of spindle, by twirling it between the right-hand and the thigh, which is suffered to continue revolving when suspended by the thread, which the spinstress gradually lengthens with her fingers.

In wheel-spinning, a small portion of the combed wool or sliver is laid across the finger, from the centre of which, called the twitch, the thread is drawn out. About thirty years since, the counties of Norfolk, Suffolk, Hertfordshire, and Essex, not only supplied all the yarn that was wanting for the manufactures of those districts, but sent large quantities of worsted yarn to Halifax and Manchester. At present the trade is completely turned, and, as we have before stated, the greater part of the yarn used at Norwich is sent there from the northern counties of England. This change has occasioned great distress in the villages where the yarn was formerly spun, by depriving the wives and children of the cottagers of their common employment.

Until the middle of the last century, worsted goods were manufactured in considerable quantities in Warwickshire, Oxfordshire, and Northamptonshire; but about that time the extension of the worsted trade in the West Riding of Yorkshire, particularly at Halifax, Bradford, and Wakefield, gradually drew this trade in a great measure away from those counties. The manufacturers in Yorkshire, or rather the merchants who bought the worsted pieces from the manufacturers, were, however, long unacquainted with the best modes of dyeing and dressing them; they were therefore sent to London or Coventry to be finished, but afterwards they were finished in Yorkshire. The demand to Spain, Portugal, Italy, and the Levant, took off the greater part of the worsted goods manufactured at Halifax; those manufactured round Wakefield and Bradford, consisting chiefly of tammies and shalloons, were consumed principally by England and her colonies. The Piece-hall at Halifax was first opened about the year 1780; and the intervening time, from thence to the year 1792, or the breaking out of the French war, may be regarded as the most flourishing era of the worsted trade in Yorkshire. Though the cheapness of calicoes, as an article of female dress, since the improvements in the cotton manufacture, materially abridged the sale for some kinds of worsted goods in England, this was more than compensated by the increased demand for carpets with worsted warps, and other articles of luxury, in which worsted yarn was employed.

The demand in foreign markets, from the year 1782 to 1792, for English worsted goods, greatly exceeded that of any former period; but after the breaking out of the French war, the worsted trade at Halifax began to decline. The greater part of the foreign markets being closed against us, most of the mercantile houses engaged in the export of worsted pieces were in consequence ruined or declined; the trade altogether, and many of the small manufacturers, engaging in the cotton trade. The introduction of English calicoes into Turkey and other parts tended also to lessen the regular demand for shalloons and other worsted goods, as articles of female dress, in those countries. Soon after the breaking out of the French war in 1792, the spinning of worsted by machinery was established at Bradford and the vicinity; and continuing to increase, drew round that place the manufacturers of worsted goods on the decline of the Halifax trade. Bradford is now become the principal seat of the worsted manufacture in Yorkshire; and some of the proprietors of the worsted mills, besides supplying the smaller manufacturers with yarn, employ a very great number of looms themselves, and carry on this branch of trade on a scale of extent never before known in the worsted manufacture. Within the last two years, the worsted trade has also greatly revived at Halifax.

The following are the kinds of worsted pieces at present principally made in Yorkshire.

Bombazets are woven both plain and twilled, with the warp of single thread; they were pressed, and finished without glazing: the width 22 inches, length 29 yards.

Tammies, or *durants*, with single warps twilled, and generally coarser than twilled bombazets: width from 32 to 36 inches, length 29 yards.

Shalloons are woven with a twill, and have a warp of single thread. We believe the name was derived from Châlons in France. The pieces are from 32 to 36 inches wide, and 29 yards long.

Cubicas are very fine shalloons so called.

Sayes, or *anascottes*, are twilled and made with single warps; they are of two kinds, one running 27 inches wide and 30 yards in length, the other 42 inches in width and 44 yards in length.

Moreens are woven plain and watered or embossed, and are made very stout, being principally used for furniture: their width is 28 inches, length 24 yards.

Calimancoes are woven plain and striped: width 17 inches, length 29 yards.

Camlets are both plain and twilled: width 18 inches, length 29 yards. They are shorter than bombazets, but not many are made in Yorkshire with doubled warps.

Lastings have doubled warps, sometimes of two and sometimes of three threads, and are made with great variety of patterns, either plain, twilled, or flowered, and are distinguished by different names, according to their figures and

quality; as prunelle, amens, (probably from Amiens in France, where they were manufactured,) and drawboys: the width 18 inches, length 30 yards.

Worſted ſhag, or velvet woven like corduroi and cut, is made principally at Banbury, in Oxfordſhire, and at Coventry; but has been manufactured alſo in Yorkſhire.

In the worſted manufactures of France, there were greater varieties of pieces than in England. One kind of camlet, made with a fine warp from the wool of the Angora goat and a weft of fine worſted, was remarkably beautiful; but we believe it has not been manufactured in Yorkſhire or at Norwich.

For ſome account of the worſted manufactures of France, ſee WOOLLEN *Manufacture;* under which article we have given the hiſtory of the worſted manufacture as connected with the woollen, and where may be ſeen the number and value of the worſted pieces exported from England in the year ending January 1817. See alſo *long combing-wool,* under the article WOOL.

WORSTED *Spinning.* In the article WOOL we have given an account of the different kinds of long wool which are proper for ſpinning into worſted, alſo the manner of ſorting and ſcouring them. This wool muſt be prepared for ſpinning by repeated combings, with a comb or heckle that is provided with a great number of long ſteel pins which are ſharp-pointed. Theſe points being few in number compared with the teeth of cards, they can be ſafely introduced between and drawn through the long fibres of the wool, in order to ſeparate and ſtraighten them, without materially breaking them. Another object of the combing is, to ſeparate the ſhort fibres which are intermixed with the long ones; for in ſpinning any kind of thread, it is deſirable that the fibres ſhould be all as nearly as poſſible of a length.

Wool-combing.—In the ordinary proceſs of wool-combing by hand, the implements uſed are, 1. Two combs for each workman. 2. A poſt, to which either of the combs can be fixed, to ſupport them during the operation. 3. A comb-pot, which is a ſmall ſtove to heat the teeth of the combs, which is found to facilitate the combing. The combs are ſhewn at *fig.* 1. *Plate* I. *Woollen Manufacture:* each comb is compoſed of two rows of pointed ſteel teeth, *a* and *b*, diſpoſed in two parallel planes. One of the rows contains longer teeth than the other. They are fixed into a wooden ſtock or head *c*, which is covered with horn, and has a handle *d* fixed into it, perpendicular to the planes of the rows of teeth. The rows of teeth are about ſeven inches long, and each row contains about twenty-four teeth. The length of the longeſt teeth is near twelve inches, and the ſhorter ones about eight inches. The teeth are made of ſteel, of a round figure, and regularly tapering from the baſe, where they are fixed into the ſtock, to the point, which is quite ſharp. The teeth are about one-ſixth of an inch in diameter at the baſe; and the interval between the two adjacent teeth at the baſe is rather leſs than their diameter, or one-eighth of an inch. The ſpace between the two planes in which the teeth are diſpoſed is about one-third of an inch at the baſes of the teeth. The teeth ſhould be ſtraight and well-tempered, and poliſhed. If they become crooked in working, the workman muſt ſtraighten them, and ſet them all in a true line. The combs uſed for the laſt combing of the wool have three rows of teeth.

In the wool-comber's ſhop a poſt is fixed, as ſhewn by *fig.* 2, in order to ſupport the combs occaſionally during the working. An iron ſtem *g* is fixed faſt into the poſt, and projects horizontally from it; the extreme end of it turns upwards with a point, which is inſerted into a hole through the middle of the handle of the comb. Alſo at the other end of the ſtem *g*, cloſe to the poſt, there is a ſmall hook *b* rivetted, which terminates with a pointed pin, ſituated in an horizontal direction. This point is inſerted into a hole made in the end of the handle of the comb, in the direction of its length. The end of the comb-handle being firſt placed on the point of the hook *b*, it is let down upon the other point *g*, which, by paſſing through the handle, fixes the comb quite faſt to the poſt, as ſhewn at *fig.* 2.

In the operation of combing wool, it is neceſſary to heat the teeth of the combs, in order to ſoften and relax the fibres of the wool, and render them more eaſy to work. The heat alſo tends to diſtribute the oil with which the wool is lubricated. The combs are heated in a comb-pot or ſtove, *fig.* 3, which is a ſmall furnace built in brick, to incloſe a fire-place, of which A is the door, B the aſh-pit, and C the flue. Above the fire a circular caſt-iron plate *a a* is placed. This is made flat, except in the central part, where there is a concavity, to obtain a better action of the fire. Immediately over the plate *a*, another plate, *b b*, is placed parallel to the former, but with a ſufficient ſpace between them to admit the teeth of the combs: ſeveral pieces of iron are placed between the two plates, to keep them at a proper diſtance aſunder, and to divide the ſpace into ſmall cells proper for the combs.

In uſing this ſtove, the workman muſt be careful not to heat it too much, and a damper in the flue is very uſeful to regulate the draught; if the heat is too great, it ſpoils the temper of the comb-teeth, and injures the wool alſo. The moſt improved ſtove is heated by ſteam, which will give a ſufficient warmth, but cannot overheat the combs.

In order to comb the wool, it is ſeparated into handfuls, each containing near four ounces of wool, which is about a proper quantity to be combed at once. Theſe handfuls are ſprinkled with oil, and the wool is rolled in the hands to diſtribute it equally. The quantity of oil varies from $\frac{1}{30}$th to $\frac{1}{16}$th of the quantity of wool by weight. The comb is firſt heated by introducing the teeth into the ſtove, in one of the cells between the two iron plates; when it has acquired ſufficient heat it is withdrawn, and another comb is put in its place. The heated comb is then faſtened to the poſt, with its teeth pointing upwards, in order to be filled with wool; the comber takes one-half of the handful of wool in his hand, and catches it upon the teeth of the comb by throwing the wool over the points, ſo that they penetrate it; then by drawing the wool towards him, and at the ſame time downwards to the bottom of the teeth, a portion of the wool will remain in the teeth. The lock of wool is again caſt upon the teeth, and drawn through them, and every time ſome wool remains; this is repeated as often as is neceſſary, until all the wool is gathered upon the teeth. The comb thus filled is placed with its points in the ſtove, and the wool which is upon it remains outſide of the ſtove, but will become ſlightly warmed. The other comb, which was heating whilſt the firſt was filling, is now filled in turn, in the ſame manner as the firſt, and is then put to heat with the wool upon it, and whilſt this is going on, the workman occupies himſelf in making a handful ready for the next combing.

When both combs are properly warmed, the comber holds one of them with his left-hand over his knee, as he is ſeated on a low ſtool, and with the other comb held in his right-hand he combs the wool upon the firſt, by introducing the points of the teeth of one comb into the wool contained in the other, and drawing them through it; this is repeated for 14 or 15 ſtrokes, until the fibres of the wool are ſeparated, diſentangled, and laid parallel. In combing, he di-

rects the combs sometimes with the teeth of one parallel to the teeth of the other, and sometimes with the teeth of the two combs at right angles, or in a cross direction; but in all cases he must take care to begin gradually, by introducing the points of the teeth, first into the extremity of the wool which is contained in the teeth of the comb, and then penetrating deeper into the wool at every succeeding stroke, till at last he works the combs as near as he possibly can without actually bringing their teeth in contact: without this precaution, he could not draw the comb through the wool without breaking the fibres, and tearing the wool out of the teeth of the comb; but if he proceeds cautiously, the wool will be disentangled, separated, and straightened.

During the working, he frequently changes the combs, so as to work the wool upon both combs; but as the wool will gradually accumulate upon that comb which is most worked, he manages them so that at the end of about 35 or 40 strokes nearly all the wool will be gathered upon one of the combs, and will hang from its teeth in a fair lock of straight and regular wool. This comb he puts to heat for a moment, then fixes it to the post, and proceeds to draw off the wool from the comb in a sliver. To do this, he takes hold of the wool which projects from the teeth with the fingers and thumbs of both hands, and draws it away from the teeth of the comb in a direction perpendicular to their length, without sliding it off their points: as the wool comes away, he takes fresh hold, always seizing the wool at a given distance from the teeth. A portion of the wool which consists of short fibres will not come off, because it does not reach to the place where the comber grasps the wool; it therefore remains in the teeth of the comb, and is drawn off afterwards. This short wool, which is called noil, is unfit for worsted spinning; it is composed in part of the short fibres which are naturally intermixed in the long ones, and also of the fragments of long fibres which are broken in the process of combing. The quantity of the noil depends upon the kind of wool, and also on the care with which the comber has conducted his process; but it will seldom exceed $\frac{1}{8}$th or $\frac{1}{9}$th of the quantity of the raw wool by weight.

The wool which is drawn off from the comb forms a continued sliver or band, the fibres of which are straight and parallel, but not sufficiently so for spinning; it is therefore combed over again, and frequently it is repeated a third time. The first combing is called hacking, and the slivers produced by it are extended five together upon a table; then holding them down with one hand, they are broken again into handfuls by drawing them with the other. These are combed again in the manner before described, but the heat given to the combs is much less. The ultimate sliver, which is drawn off from the comb the last time, should be very even, and composed of long and parallel fibres. On examining it against the light, every part should appear equally dense, without any entanglements of the fibres, for on these particulars the perfection of the spinning will in a great measure depend.

The combed wool produced from sixteen pounds of wool usually weighs eleven or eleven and a half pounds, for about two pounds are lost in washing, and the rest in noil and waste in the combing. When the combing is finished, the slivers are formed into six parcels, each containing ten or eleven slivers, which are rolled up together into a ball, and ticketed with their weight and quality, the wool-comber's mark, and wool-stapler's mark. In this state, combed wool is called tops or Jersey, and is sold to the spinners in the country, and in cottages, who spin it into worsted-thread by the simple hand spinning-wheel; but the manufacturers who spin by machinery have wool-combers at their mills, and they usually employ combing-machines in addition.

Combing-Machines.—The first combing-machine was invented by the Rev. Edmund Cartwright. His first two patents were in 1790, and he had another in 1792; but the machine was not rendered perfect, or brought into extensive use, till a later period: and in 1802 he obtained an act of parliament to renew or extend the term of his patent. The specification which he enrolled in consequence contains drawings and descriptions of machines nearly of the same kind as those which are now in use at many of the great worsted-mills, and which we shall describe. Mr. Cartwright proposed to form the raw wool into continued slivers, by joining the pieces of wool together, and slightly twisting them, and in this state they could be presented to the combing-machine; but as this plan was not found to succeed, it was found necessary to comb the wool first by hand, in order to reduce it to slivers. This is still the common practice, and takes away great part of the advantage of the machine; but we have seen a preparing-machine for this purpose, which operated very well upon the raw wool. The inventor's name we have not learned; but the rudiments of it are to be found in Mr. Cartwright's specification of 1790.

Preparing-Machine.—The raw wool is spread upon a horizontal feeding-cloth, which is extended over two rollers, and circulates upon them: by its motion, the wool is carried forwards, and presented to a pair of fluted rollers, which draw it in. This feeding-cloth is situated at the top of the machine, at the height of about five feet from the floor, so as to allow room for the rest of the machinery beneath it. A principal part of the machinery is carried by a horizontal wheel of five feet diameter, which is mounted upon a vertical axis, and is turned rapidly round by the mill. This wheel carries four porcupines, which are small cylindrical rollers, armed with spikes or teeth rather hooked. The rollers are situated horizontally in the plane of the wheel, with their length nearly in the direction of radii. They are about seven inches in diameter, and fourteen inches long, and are fixed upon horizontal spindles, which proceed from the circumference of the great wheel nearly to its centre, one extremity of each spindle being sustained by the rim of the wheel, and the other in a support fixed to the perpendicular axis. The porcupines are fixed on the ends of the spindles, near the circumference of the wheel; and on the opposite end of each spindle is a small cog-wheel, to work in a worm or endless screw, which is fixed concentric with the axis, being cut on the outside of a hollow tube, through which the vertical axis passes.

By this means, the four porcupines which the wheel contains have a two-fold motion, *viz.* they are all carried round in a circle by the motion of the wheel, and at the same time each one has a slow rotative motion on its own axis, in consequence of the cog-wheels, which work in the threads of the fixed worm.

The feeding-cloth is so situated, that the four porcupines in the great wheel will pass in succession exactly beneath the fluted rollers, which take the wool from the feeding-cloth; and the teeth of the four porcupines being sharp-pointed, and rather bent forwards at the points, they penetrate and catch the wool as it comes through these fluted rollers, and hangs down from them. A portion of wool is thus carried away by each porcupine every time it passes beneath the fluted rollers; but by the slow revolving motion of the porcupines on their own axes, each one presents a different row of teeth every time, and thus by degrees they become clothed with the wool which they take up.

This wool they deliver to a larger porcupine, which is placed beneath the revolving-wheel, or on the oppofite fide to the feeding-cloth. This porcupine is a cylinder nineteen inches diameter, and fourteen inches long: its axis is placed horizontally, and directed nearly to the centre of the vertical axis; fo that the fmall porcupines will be parallel to the large one when they pafs over it. The great porcupine is furnifhed with rows of teeth exactly fimilar to thofe of the fmall ones, which teeth are not very numerous, but large and fharp-pointed, and rather hooked, with the points forwards. When the fmall porcupines pafs over the large one, there is fo little clear fpace between their teeth, that the wool which is contained in the teeth of the fmall ones will be taken off by the large one, and remain in its teeth. The reafon of this is, that the teeth of the large porcupine prefent themfelves to the teeth of the fmall ones with the points forwards, and the fmall porcupines at the fame time move with the points of their teeth backwards. It was before ftated, that the porcupines move with the points forwards when they take the wool from the feeding-rollers, but this wool is applied on the upper fide of the porcupines, and the great porcupine is at the lower fide; hence the direction of the teeth is reverfe in the two cafes, and occafions the wool to be given to the great porcupine, a fmall quantity at a time, from each of the fmall porcupines, as they pafs over it. The great porcupine being turned flowly round upon its axis clothes itfelf with the wool in a continued fleece, and this is drawn off from its teeth by a pair of fluted rollers, between which it paffes in a continued fliver or band; this band is alfo conducted through a fhort tube, which revolves round its axis, and rolls up the fliver, to make it adhere better together in a round and compact form.

The action of this machine is not to comb the wool, but to divide the mafs of raw wool, which is fpread on the feeding-cloth, into a great number of fmall and equal portions by the fucceffive ftrokes of the fmall porcupines; thefe portions are again mixed together in one film of wool upon the great porcupine, from which the wool is drawn off in a continued fliver, and as much twift is given to it as is requifite to make the fliver fufficiently compact to fubmit it to the combing-machine.

Cartwright's Combing-Machine, or *Combing-Table;* called alfo amongft the workmen *Big Ben.*—In *Plate* II. *fig.* 1. *Worfted Spinning*, is a horizontal plan of the machine, which exhibits nearly all its parts; we have alfo given a perfpective view in *fig.* 2. of the operative parts, as they would appear if detached from the framing which fuftains them. A A is a circular ring of wood, which is fixed down on the framing; B B is a fimilar ring, which is fitted into the fixed ring, with liberty to turn round within it. The interior of this ring is furnifhed with a row of comb-teeth, with the points directed to the centre, and there are two other rows of fhorter teeth beneath, fo as to make three circular rows of teeth. This forms a large circular comb, called the combing-table, about five feet diameter; it is moved flowly round in the direction of the arrow by means of a pinion, which works into a ring of cogs, fixed in fegments withinfide of the circular comb beneath the row of teeth, as is fhewn in the fection, *fig.* 3.

The wool is filled upon the teeth of the circular comb by means of two machines F and G, called crank-lafhers. Thefe fupply the wool by lafhing or throwing the lock of wool upon the teeth of the comb, and then drawing up the wool from the comb, with a motion very fimilar to that of the hand of the workman in filling the combs, as we have before defcribed. The crank-lafhers repeat their ftrokes with great rapidity; but as the comb-table is kept in continual motion, the wool which is lafhed upon the teeth by the firft crank-lafher F is carried away, and in its courfe comes beneath the other crank-lafher G, by which more wool is filled upon the teeth, and they receive the intended portion. This wool, by the rotation of the comb-table, is then carried beneath a fmall comb K, which works by a crank movement, but with its teeth always horizontal; they penetrate through the wool, and then rife up fo as to comb it. After this operation, the wool is taken off from the teeth of the comb-table between a double pair of fluted rollers N, fituated immediately over the comb-teeth; thefe draw off the combed wool in a continued fliver, which is conducted through another pair of plain rollers R, and falls into a tin can placed there to receive it.

This machine was not found capable of combing the raw wool, chiefly becaufe the comb-teeth are not heated, and alfo becaufe the actions of lafhing on the wool, and afterwards combing it, begin to act upon wool, at firft with their full force, and break the fibres if they are entangled together; hence it is found beft to comb the wool by hand once over, or for fine goods twice. The wool is thus formed into flivers, which are joined together, by laying them on a table, with the ends lapped over each other; and rolling them together, they will join into one long fliver. Three of thefe flivers are put into tin cans *i i*, which are placed upon a circular table I, and carried upwards to the crank-lafher F or G, which are both of fimilar conftruction. The table I is mounted on an axis, fo as to be capable of turning flowly round horizontally, in order to twift the three flivers together into one; but in the machines which we have feen in ufe, this movement is commonly neglected, for if the flivers are prepared by hand-combing, as we have before defcribed, they will hang together without twifting.

The flivers, which are carried up from the cans to the crank-lafher (fee *fig.* 3.), firft pafs over a roller at *e*; the axle of this roller is alfo the fixed centre of motion of a trough H, which forms one part of the crank-lafher. The fliver of wool is conducted along the trough H, and then turns over a fecond roller at *f*; the centre-pin of this roller is the joint, which unites the end of the trough H with a moveable frame *d d*, which has a tube *g* fixed in front for the fliver of wool to pafs through. A little below the middle of this frame *d d* are holes through its fides, to receive the pin of a crank *b b*, of which the central axis is fupported in bearings fcrewed to the frame of the machine, and it is turned round by the power of the mill. By means of a pair of bevelled wheels D and E, *fig.* 1. the cranks of the two crank-lafhers are connected together, and have a common motion, but in a direction at right angles to each other. At the lower end of each of the moving frames *d d*, a pair of fluted rollers *i* are fixed, which draw the fliver between them. The rollers are put in motion by means of a cog-wheel *k*, fixed on the extremity of the axis of the lower roller; this is turned by a fmall pinion, fixed at the end of an axis, which paffes through the frame *d d*, and which at the oppofite end has a wheel *h*, that receives motion from a pinion fixed faft to the pin of the crank. The upper of the two fluted rollers is preffed down againft the lower one by fprings, which bear on its pivots with fufficient force to hold the wool firmly between them, and draw the fliver forwards when they turn round.

The motions of the crank-lafher are not eafy to be underftood from a verbal defcription. It muft be recollected, that the upper end of the frame *d d* which carries the rollers, being jointed to the end of the trough H, it muft always move in the arch of a circle, as fhewn by the dotted lines, *fig.* 3; the centre of this arch is *e*: alfo that the middle part of the frame *d*, where the crank-pin paffes through

it, muſt deſcribe a circle when the crank revolves: in conſequence, the rollers *i*, which are at the lower end of the frame, will move in a curve, as ſhewn by the dotted lines. It is an oval or diſtorted ellipſis, with the longeſt diameter horizontal.

At the ſame time the fluted rollers circulate in this orbit, they are in continual motion on their own axis, by the communication of wheel-work before deſcribed, and they draw the ſliver of wool down the tube *g*; the end of the ſliver, which projects from below the rollers, hangs down from them in a lock, and by the motion of the crank-laſher this is thrown againſt the points of the teeth in the comb-table. At the period when the wool is thus thrown on the teeth, the rollers are moving nearly in an horizontal direction, ſo as to draw the wool in the direction of the length of the teeth, and they penetrate the wool; but as the rollers proceed in their elliptic orbit, they begin to riſe and draw the wool upwards away from the teeth in an inclined direction, as is evident by tracing the dotted courſe marked out for the rollers. By thus drawing up the wool between the teeth, a portion of the wool will be left in them; the rollers then riſe up rapidly in their oval courſe, and the wool is raiſed quite above the teeth; the rollers then move forwards to make another ſtroke, and during ſuch advance, the rollers, being in continual motion, draw forwards the ſliver of wool, and the end hangs down ready to be laſhed on the teeth of the comb next time.

The motions of the ſmall comb K muſt be next deſcribed. The whole machine receives its motion by means of a wheel or pulley *c*, *fig.* 1, upon the axis of the crank for the laſher G; D and E are the bevelled wheels by which the other crank is turned; at the extreme end of the axis C is a pinion, which turns a bevelled wheel L, and on the axis of this is a wheel turning two others M M of equal ſize; on the extremities of the axes of the wheels M M are two cranks *l l* of equal radii, which are both jointed to an iron bar *m m*, and both turning round together in the ſame direction, they cauſe the bar to move in a direction parallel to itſelf, and every part of the bar deſcribes a circle equal to the radius of the cranks. The ſmall comb K is fixed to this bar, and partakes of its motion, whereby the points of its teeth are carried horizontally into the wool contained in the teeth of the great comb, then riſe upwards and draw through the fibres, in order to comb them.

In order to remove the little comb when it becomes filled with wool, it is attached to the bar *m* by means of a comb-holder or ſocket L, which has a groove at each end to receive the little comb, and it can be mounted or withdrawn at pleaſure. This ſocket L is moveable upon a horizontal pin fixed at the end of the bar *m*, ſo that it can be turned with either end upwards; and as the little comb can be fixed at either end of the ſocket, a ſpare comb is placed in the upper groove of the ſocket, whilſt the lower groove holds the comb which is in uſe; but when this becomes filled with wool, which it has gathered from the comb-table, the ſocket L is inverted by turning it half round upon its centre-pin, and by this means the freſh comb is brought down into uſe, and the other can be taken away to clear off the wool from it. There is a ſmall bolt fixed to the pin on which the ſocket L turns, which can be ſhot into a notch when the ſocket is in a perpendicular poſition, and will then hold the ſocket faſt from turning, and keep the comb in a proper poſition for its work. In this way, the little comb can be taken away and replaced by a freſh one as often as is neceſſary, without ſtopping the machine, for the ſmall comb does not move very quick. The ſame boy who attends to change the combs, when neceſſary, alſo ſets up the wool in the great comb-teeth with a ſmall ſcraper, ſo that the ſmall comb will penetrate through it with more certainty and effect. The plane of the rows of teeth in the ſmall comb is not horizontal, or parallel to the teeth of the combing-table, but inclined thereto, ſo that thoſe teeth of the ſmall comb which firſt come into action upon the wool do not penetrate deeply into it; but as the comb-table turns round, the wool advances beneath the ſmall comb, and is operated upon thoſe teeth which go deeper, and the laſt teeth of the comb go as deep as they can, not to touch the teeth of the comb-table.

The wool is now combed, and only remains to be drawn off in a continued ſliver; this is done by the drawing-off rollers N, which are fluted iron rollers, placed horizontally over the comb-teeth, and nearly in the direction of a radius of the comb-table: they are ſupported in an iron frame, and are turned round by a pair of bevelled wheels from a vertical axis P. This axis extends the whole height of the machine, and is put in motion by means of a pair of bevelled wheels, and an oblique axis Q, which is turned by a bevelled wheel and pinion on the extreme end of the axis of the firſt crank-laſher.

The great comb receives its motion from the perpendicular axis P, which turns a large wheel T by a pinion on the lower end of it: on the upper end of the axis of this wheel is the pinion which works in the ring of teeth withinſide of the comb-table: in this way, a very ſlow motion is given to the comb-table. There are two pair of drawing-off rollers N, ſituated cloſe together, and parallel to each other; the firſt pair are put in motion as we have deſcribed, and the back pair are turned by means of equal cog-wheels, ſo that they move with the ſame velocity.

The wool upon the comb-table is gathered in the hand, to form a ſliver, and the end is introduced between the rollers, which continually draw off the wool as the comb-table turns round. After paſſing through both pairs of rollers, the ſliver is conducted through a forked iron, then through a round wooden tube, and is at laſt delivered by two plain wooden rollers R into a tin can placed beneath to receive it. Theſe rollers are alſo turned by bevelled wheels on the perpendicular axis P. The drawing-off rollers only take away the long wool, the fibres of which are long enough to reach to the rollers. The two rollers compoſing the front pair of drawing-off rollers are not placed immediately over each other, but the upper roller overhangs the lower one, ſo that the plane in which the axes of the upper and lower rollers are both ſituated is inclined at about an angle of 45 degrees to the plane of the comb-table: by this means, the wool is drawn off from the comb, at an angle of 45 degrees, to paſs between the rollers.

The noils, *i. e.* the ſhort wool and broken fibres, which will not reach the drawing-off rollers, remain in the teeth of the comb-table, and alſo as much of the long wool as is on the lower ſide of the comb, and theſe are called backings: both are taken off by a boy, who is ſeated for that purpoſe within the circle of the comb-table; he firſt draws off the backings from beneath the comb, and then, with one hand above the teeth, and the other below, he draws off the noils.

Theſe two ſorts of wool are handed to a boy on the outſide of the machine, who puts them into ſeparate boxes. The backings are filled on the ſmall combs before they are put into the machine, and become ſomewhat combed by the action of the ſmall comb: when the ſmall combs are removed from the machine, the wool upon them is further combed by hand, and then drawn off from them in a continued ſliver, by means of an additional piece of machinery, which is at the ſide of the machine.

This combing-machine is found to break the fibre of the wool, and it increafes the quantity of noil very much, unlefs the wool is previoufly combed once or twice by hand; and as it then becomes only a fubftitute for the fecond or third combing, it faves little or no expence. The advantage of the machine is found, in the great regularity and equality of the fliver which is produced by it, a circumftance of particular importance for fine fpinning. In combing by hand when the fliver is drawn off, thofe fibres which the comber firft takes hold of are longer than the others; then as the fliver continues to be drawn, fhorter fibres are found in it, and the fhorteft are laft of all. Thefe are called the long and fhort ends of the fliver; the fhort end is always marked by twifting or rolling it up, in order that when the flivers are joined together into one for fpinning, the long and fhort ends may be equally intermixed and difperfed throughout the whole length. In drawing off the wool from the combing-machine, the long and fhort fibres are intermixed and taken up together, fo that the fliver is of very equal texture.

There have been feveral other attempts to make combing-machines which deferve notice, though they have not come into ufe.

Meffrs. Wright and Hawkfley had a patent in 1793 for a combing-machine; and Mr. Toplis of Cuckney had alfo a patent of the fame date, which contains fome good ideas. Mr. Hawkfley, in 1797, had a patent for improvements on Cartwright's: the principal one was, to make the combing-table by the combination of a number of fmall combs, which could readily be applied to the table, or detached at pleafure. If this would allow the combs to be heated, as the inventor propofed, they would work much better.

Mr. Amatt had a patent in 1795, and Mr. Pearce in 1798: after this time, Mr. Cartwright's machines had received fome improvements from Mr. Hawkfley, and came into ufe; and we find lefs fpeculation on the fubject.

Gilpin's Combing-Machine.—In 1811, Mr. George Gilpin of Sheffield perfected a very ingenious machine, which combed the raw wool in a moft complete manner. We do not hear that this machine is yet come into ufe, although we have no doubt of its anfwering the purpofe, having frequently examined it while at work: its only fault was a complication of parts, which might be eafily removed.

The outline of this machine is taken from that of Mr. Toplis in 1793, but is very much improved and perfected. *Fig.* 4. of *Plate* I. *Worfted,* is a fketch of the principal parts. The machine works with eight combs at once, which are of rather larger fize than the ordinary hand-combs, the rows of teeth being twenty inches long. Thefe combs are fixed upon two reels or frames A, B, which revolve upon their axles by the power of the mill; four combs, D and E, are fixed upon each reel, and in fuch pofition that both ends of the comb-teeth, *viz.* the points and roots, are equally diftant from the centre of the reel to which they are fixed; and the reels, with the combs fixed upon them, form two revolving wheels or frames. The combs D and E are fo made, that they can be detached from the reels, or replaced and fixed faft in a moment, by the attendants; and they can, therefore, be heated in a ftove, in the fame manner as the hand-combs. The wool is alfo filled upon the combs by hand, and the combs and wool are heated in the ufual manner before they are put into the machine, in order to comb the wool.

One of thefe reels A is fimply turned upon its axis, but the other reel B has a curious compound motion given to it by the machinery: thus it revolves on its own axis; but the axis alfo advances to, and recedes from, the other reel with a motion parallel to itfelf, which is repeated four times in every revolution. Whilft B advances towards A, it moves with only one-third of the velocity with which it returns from A. The advancing movement is of a limited and conftant extent; but at the fame time, there is a third movement which regulates this extent, fo that at every fucceeding ftroke which the machine makes, the two reels will approach nearer together.

Suppofe all the combs filled with wool, and mounted in their places upon the reels, the machine is then put in motion, and the two reels A and B turning round in oppofite directions, their combs D and E meet each other; and by the compound movement of B, (*viz.* advancing flowly towards A, and turning round at the fame time,) the combs D and E approach in fuch a manner, that the points of each comb penetrate the wool which is in the other comb, and this is reciprocal of both combs. When the teeth are thus entered into the wool, the moveable reel B retreats quickly from the other, and the teeth, by drawing through the wool, comb and feparate its fibres.

The circular motion of both reels is not regular and equable, but is communicated by means of elliptical cog-wheels, which occafion the reels to move round very flowly, at the moment when the comb of the reel B is drawing out or combing the wool; but this motion being finifhed, the reels begin to turn round more rapidly, and at the fame time the reel B approaches towards A with a flow movement, in order to prefent another pair of combs to each other, which meet; and each one penetrates the wool which is upon the other, and then the reel B draws out to comb it, in the manner before defcribed.

In this way they continue to make fucceffive ftrokes, until the wool is fufficiently combed: the machine is then ftopped, and the combs taken off one by one, to be replaced by others, which are filled with frefh wool, and properly heated.

There is likewife another movement of the reel A, which we have not yet mentioned: the axis of that reel has a flow motion backwards and forwards, endways in the direction of its length, for a fhort diftance. The intention of this is, that the fame parts of the combs fhall never come oppofite to each other at two fucceffive ftrokes.

It fhould be obferved, that when the machine is firft fet to work, the combs at their point of meeting do not come within three or four inches of each other, and the points only penetrate amongft the longeft fibres of the wool upon the combs; but at every ftroke which is made, the combs advance nearer together, and take deeper into the wool, until, after a certain number of ftrokes are made, the combs approach as near as they can without touching. They continue to work in this manner for fome time, and when the intended number of ftrokes is made, a bell rings as an indication that the machine fhould be ftopped. This is done by drawing a lever, and in confequence the machine will ftop itfelf in the exact pofition for changing one of the combs on each reel. Thefe are removed, and others ready filled with wool and heated are put on in their places, which being done on both reels at the fame time by two perfons, is only the work of a moment. The machine is then put in motion again, but by the machinery it will ftop itfelf again at the required pofition for changing the next pair of combs; it is then put forwards, and fo on, until all the eight combs are changed.

The combs which are removed from the machine are put into the ftove to heat for a few moments, and then the wool is drawn off from them by a feparate machine. The head of the comb is here placed in a perp dicular groove, fo that its teeth ftand horizontal; and a piece

of metal, which is fixed to the head of the comb, and projects therefrom like a tooth, enters into the ſpiral groove of a ſcrew, which ſtands in a perpendicular poſition, and is continually turned round by the machinery. By this means, the comb is regularly and ſlowly let down in the groove, from top to bottom. A pair of fluted rollers is placed horizontally, and parallel to the teeth of the comb, in ſuch a poſition that the comb, in deſcending, will paſs with its teeth at a proper diſtance from them, to draw off the wool in a ſliver. After paſſing through theſe fluted rollers, the ſliver is conducted through a perpendicular revolving tube, which gives a roundneſs to it, the ſame as it would acquire by being rolled between the hands, and then it is conducted between a pair of plain rollers, which deliver it into a tin can placed before the machine.

A wooden roller is placed above the fluted rollers, with eight pieces of board projecting from it in the direction of radii. When the roller turns round, theſe boards act to ſtroke the wool upon the comb, and raiſe it into a proper ſituation to be drawn off by the fluted rollers.

The combs are prepared for drawing off the wool, by heating them as before mentioned, and by ſliding the wool from the roots of the teeth half way towards their points. In this ſtate, the combs are carried one by one to the drawing-off machine, and the head of one comb is put into the top of the perpendicular groove: it will be prevented from falling down in the groove by the projecting tooth, which enters the ſpiral groove of the perpendicular ſcrew. The wool is gathered up and introduced between the fluted rollers; the machine is then put in motion, and by means of the ſcrew the comb is gradually lowered down, and the wool is drawn off from it in a ſliver, which is rolled up into a compact form by the revolving tube, through which it paſſes, and is delivered into the can by the plain rollers.

The attendant holds another comb ready to follow the firſt, and when the firſt has deſcended to a certain point, he ſlips the next comb into the perpendicular groove, ſo that it reſts upon the former, and the wool upon the two combs joins as it were in one. The ſtroker, when they paſs before it, lays the fibres all one way, and the wool is drawn off by the rollers in a continued ſliver, which does not preſent the ſlighteſt appearance of joinings. Another comb is then put in, and the wool joins to the former, and ſo on. The backings, or wool at the back of the comb, are drawn off by the boy ſtationed behind the machine; and the combs, as they come through below, are received by boys, who afterwards take away the noil or ſhort wool which remains in the teeth, and then put the combs back into the ſtove to heat them, ready to be filled again, in order to proceed with another combing. When the wool of all the eight combs is drawn off, the motion of the drawing-off machine is ſtopped at the moment when the eighth or laſt comb has deſcended half way through its courſe. In this ſtate, the machine waits till another combing is finiſhed, and then the ſucceeding comb being placed on the top of that one which continues in the machine, the continuity of the ſliver will be preſerved.

The inventor of this machine ſtates in his ſpecification, that for common work the wool only requires to be operated upon once by the combing-machine; and in that caſe, the machine muſt be adapted to make twenty-four ſtrokes of each pair of combs before the bell rings. For medium work, ſuch as would require to be combed twice over, in the uſual manner of hand-combing, it muſt be combed twice over by the machine: thus, after having been combed once in the manner before deſcribed, the ſliver of wool is broken up into handfuls, and filled on the combs again by hand as before, and combed over again in a ſimilar manner; but the combs are leſs heated for the ſecond time of combing. By changing a wheel, the machine ſhould be adapted to make only fourteen or ſixteen ſtrokes before it ſtops, when it is intended to comb twice over. The wool intended for the fineſt ſpinning ſhould be combed three times over, and the machine ſhould be ſet to make fourteen or ſixteen ſtrokes of each pair of combs.

The machine has alſo two different movements for the drawing out of the moveable comb-reel: in one, the motion is over a ſpace of ten inches, and is adapted to comb ſuch wool as is ſix or eight inches length of ſtaple, and is called wether wool; but by a ſlight alteration, the excurſion of the moveable reel can be increaſed to thirteen inches, and is then adapted to comb hey wool, or wool which is from eight to eleven inches length of ſtaple.

Mr. Gilpin's machine has the advantages of heating the combs and of filling them by hand, both of which are eſſential to any machine which is propoſed to comb the raw wool. The filling is an operation which requires diſcretion, if it is expected that the long fibres ſhall be preſerved without breaking. The perſon who fills the wool on the teeth takes a greater or leſs lock of wool in his hand, according to the condition of it, and the degree of entanglement: alſo in drawing it between the comb-teeth, the force is proportioned to what the wool will bear. Mr. Gilpin's ſpecification ſtates, that under certain circumſtances, when the wool will not waſh well, but remains taggy, it is adviſeable to fill it upon the combs, and ſlip it off; then fill it again, preparatory for the machine. As the object of this firſt filling is chiefly to warm the wool, the end may be in part attained by laying the wool upon the top of the ſtove for a few minutes before it is filled.

Planking.—Let us ſuppoſe that the wool is combed either by the hand, or by the machine, and we will proceed to explain the means of preparing it into a thread. The combing-machines reduce the wool into a continued ſliver, which is ready for the drawing-frame; but the ſhort ſlivers produced by the hand-combing muſt be firſt joined together by what is called planking. Theſe ſlivers are rolled up by the combers, ten or twelve together, in balls called tops, each of which weighs half a pound: at the ſpinning-mill theſe are unrolled, and the ſlivers are laid on a long plank or trough, with the ends lapping over, in order to ſplice the long end of one ſliver into the ſhort end of another. The diſtinction of the two ends of the ſliver has been before explained; the long end being that which was firſt drawn off from the comb, and contains the longeſt fibres of the wool; the ſhort end is that which came laſt from the comb, and contains the ſhort fibres. The wool-comber lays all the ſlivers of each ball the ſame way, and marks the long end of each by twiſting up the end of the ſliver. It is a curious circumſtance, that when a top or ball of ſlivers is unrolled and ſtretched out ſtraight, they will not ſeparate from each other without tearing and breaking, if the ſeparation is begun at the ſhort ends, but if they are firſt parted at the long ends they will readily ſeparate.

Breaking-Frame.—Here the ſlivers are planked or ſpliced together, the long end of one to the ſhort end of another; they are immediately drawn out and extended by the rollers of the breaking-frame. A ſketch of this machine is given in *Plate* II. *fig.* 5; it conſiſts of four pairs of rollers, A, B, C, D. The firſt pair A receives the wool from the inclined trough E, which is the planking-table. The ſlivers are unrolled, parted, and hung looſely over a pin, in reach of the attendant, who takes a ſliver and lays it flat in the trough, and the end is preſented to the rollers A, which being in

motion will draw the wool in; the fliver is then conducted through the other rollers, as fhewn in the figure: when the fliver has paffed half through, the end of another fliver is placed upon the middle of the firft, and they pafs through together; when this fecond is paffed half through, the end of a third is applied upon the middle of it, and in this way the fhort flivers produced by the combing are joined into one regular and even fliver.

The lower roller C receives its motion from the mill, by means of a pulley upon the end of its axis, and an endlefs ftrap. The roller which is immediately over it is borne down by a heavy weight *e*, fufpended from hooks, which pafs over the pivots of the upper roller. The fourth pair of rollers D moves with the fame velocity as C, being turned by means of a fmall wheel upon the end of the axis of the roller C, which turns a wheel of the fame fize upon the axis of the roller D, by means of an intermediate wheel *d*, which makes both rollers turn the fame way round. The firft and fecond pairs of rollers, A and B, move only one-third as quick as C and D, in order to draw out the fliver between B and C to three times the length it was when put on the planking-table. The flow motion of the rollers A is given by a large wheel *a*, fixed upon the axis of the roller A, and turned by the intermediate cog-wheels *b*, *c*, and *d*; the latter communicates between the rollers C and D. The pinions on the rollers C and D being only one-third the fize of the wheel *a*, C and D turn three times as faft as A, for *b*, *c*, and *d*, are only intermediate wheels. The rollers B turn at the fame rate as A. The upper roller *c* is loaded with a heavy weight, fimilar to the rollers A; but the other rollers, B and D, are no farther loaded than the weight of the rollers.

The two pairs of rollers A B and C D are mounted in feparate frames, and that frame which contains the third and fourth pairs, C D, flides upon the caft-iron frame F, which fupports the machine, in order to increafe or diminifh the diftance between the rollers B and C. There is a fcrew *f*, by which the frame of the rollers is moved, fo as to adjuft the machine according to the length of the fibre of the wool. The fpace between B and C fhould be rather more than the length of the fibres of the wool. The intermediate wheels *b* and *c* are fupported upon pieces of iron, which are moveable on centres: the centre for the piece which fupports the wheel *b* is concentric with the axis of the roller A; and the fupporting piece for the wheel *c* is fitted on the centre of the wheel *d*. By moving thefe pieces, the intermediate wheels *b* and *c* can be always kept in contact, although the diftance between the rollers is varied at times. By means of this breaking-frame, the perpetual fliver which is made up by planking the flivers together is equalized, and drawn out three times in length, and delivered into the can G.

Drawing-Frame.—Three of thefe cans are removed to the drawing-frame, which is fimilar to the breaking-frame, except that there is no planking-table E. There are five fets of rollers, all fixed upon one common frame F, the breaking-frame which we have defcribed being the firft. As faft as the fliver comes through one fet of rollers, it is received into a can, and then three of thefe cans are put together, and paffed again through another fet of rollers. In the whole, the wool muft pafs through the breaker and four drawing-frames before the roving is begun. The draught being ufually four times at each operation of drawing, and three times in the breaking, the whole will be $3 \times 4 \times 4 \times 4 \times 4 = 768$; but to fuit different forts of wool, the three laft drawing-frames are capable of making a greater draught, even to five times, by changing the pinions; accordingly the draught will be $3 \times 4 \times 5 \times 5 \times 5 = 1500$ times.

The fize of the fliver is diminifhed by thefe repeated drawings, becaufe only three flivers are put together, and they are drawn out four times; fo that in the whole, the fliver is reduced to a fourth or a ninth of its original bulk.

The breaking-frame and drawing-frame, which are ufed when the flivers are prepared by the combing-machines, are differently conftructed; they have no planking-table, but receive three of the perpetual flivers of the combing-machine from as many tin cans, and draws them out from ten to twelve times. In this cafe, all the four rollers contribute to the operation of drawing: thus the fecond rollers B move $2\frac{1}{4}$ times as faft as the rollers A; the third rollers C move 8 times as faft as A; and the fourth rollers E move $10\frac{1}{2}$ times as faft as A. In this cafe, the motion is given to the different rollers by means of bevelled wheels, and a horizontal axis, which extends acrofs the ends of all the four rollers, to communicate motion from one pair of rollers to another.

There are three of thefe fyftems of rollers, which are all mounted on the fame frame; and the firft one, through which the wool paffes, is called the breaking-frame, but it does not differ from the others, which are called drawing-frames. The flivers which have paffed through one fyftem of rollers are collected four or five together, and put through the drawing-rollers. In all, the flivers pafs through three drawings, and the whole extenfion is feldom lefs than 1000 times, and for fome kinds of wool much greater.

After the drawing of the flivers is finifhed, a pound weight is taken, and is meafured by means of a cylinder, in order to afcertain if the drawing has been properly conducted; if the fliver does not prove of the length propofed, according to the fize of worfted which is intended to be fpun, the pinions of fome of the drawing-frames are changed, to make the draught more or lefs, until it is found by experiment that one pound of the fliver meafures the required length.

Roving-Frame.—This is provided with rollers the fame as the drawing-frames: it takes in one or two flivers together, and draws them out four times. By this extenfion, the fliver becomes fo fmall, that it would break with the flighteft force, and it is therefore neceffary to give fome twift; this is done by a fpindle and flyer. (See *fig.* 6.) A B are the two pairs of rollers, between which the fliver is paffed; the firft rollers A turn round flowly, but the others B revolve four times as quick, to draw the fliver to four times its original length; and as faft as it iffues from the roller, it is twifted by the motion of the fpindle C, and wound up upon the bobbin *a*. The fpindle C is put in motion by a whip-cord band, which paffes round the pulley *c*, and alfo round the wheel D. This wheel is fixed on a vertical axis *e*, which has a pinion on the upper end, to give motion to the lower roller B, by means of a bevelled wheel upon the end of its axis. The oppofite end of the axis has alfo a bevelled pinion upon it, to give motion to a bevelled wheel fixed upon an horizontal axis, which carries another bevelled pinion, to give motion to a bevelled wheel fixed upon the end of the axis of the back rollers A. The fizes of thefe wheels and pinions are fo proportioned, that the back rollers A turn only once to every four turns of the front rollers B, as before mentioned.

The back rollers are capable of being fet at a greater or lefs diftance from the front rollers, according to the length of the fibres of the wool, and in all cafes the diftance fhould be rather more than the length of the fibres, but not a great deal.

The ſpindle is ſupported on its point, and ſuſtained by a collar at the middle of its length. Upon the top of the ſpindle, the flyer *e* is ſcrewed; it has two branches, which turn downward, and one of them has an eye at the lower end, through which the roving is conducted, in order to lay it upon the bobbin *a*. This bobbin is fitted looſely upon the upper part of the ſpindle, and reſts with its weight upon a piece of wood projecting from the bobbin-rail *f*. The rail is made to riſe and fall continually with a ſlow motion, ſo as to preſent every part of the bobbin in ſucceſſion to the eye of the flyer, and thereby wind the roving upon every part of the length of the bobbin. The bobbin is not fixed upon the ſpindle, but is fitted looſely thereupon; and by reſting upon the piece of wood which is fixed to the bobbin-rail, there is ſo much friction and reſiſtance to the motion of the bobbin, that it gathers up the roving by winding it round itſelf as faſt as the rollers give it out. The twiſt given to the roving is juſt enough to make it hang together, and one turn in each inch is uſually enough. Some roving-frames are made with four pairs of rollers, and draw ten or twelve times; and in this way, it is not neceſſary for the ſliver to paſs ſo frequently through the drawing-frame.

Spinning-Frame.—This is ſo much like the roving-frame, that a ſhort deſcription will be ſufficient. The ſpindles are more delicate, and there are three pairs of rollers inſtead of two; the bobbins which are taken off from the ſpindles of the roving-frame, when they are quite full, are ſtuck upon wires at L (*fig.* 7.), and the roving which proceeds from them is conducted between the rollers. The back pair A turns round ſlowly; the middle pair turns about twice for once of the back rollers; and the front pair B makes from twelve to ſeventeen turns for one turn of the back rollers B, according to the pinions which are employed, and theſe can be changed according to the degree of extenſion which is required.

The ſpindles muſt revolve very quickly in the ſpinning-frame, in order to give the requiſite degree of twiſt to the worſted. The hardeſt twiſted worſted is called tammy-warp, and when the ſize of this worſted is ſuch as to be twenty or twenty-four hanks to the pound weight, the twiſt is about ten turns in each inch of length. The leaſt twiſt is given to the worſted for fine hoſiery, which is from eighteen to twenty-four hanks to the pound. The twiſt is from five to ſix turns *per* inch. The degree of twiſt is regulated by the ſize of the whirls or pulleys upon the ſpindle, and by the wheel-work, which communicates the motion to the front rollers from the band-wheel, which turns the ſpindles.

It is needleſs to enter more minutely into the deſcription of the ſpinning machinery for worſted, becauſe the conſtruction is very ſimilar to the water-frame for ſpinning cotton, invented by ſir Richard Arkwright, and which is fully deſcribed in our article *Manufacture of* COTTON. The differences between the two are chiefly in the diſtance between the rollers, which in the worſted-frame is capable of being increaſed or diminiſhed at pleaſure, according to the length of the fibres of the wool, and the draught or extenſion of the roving is far greater than in the cotton.

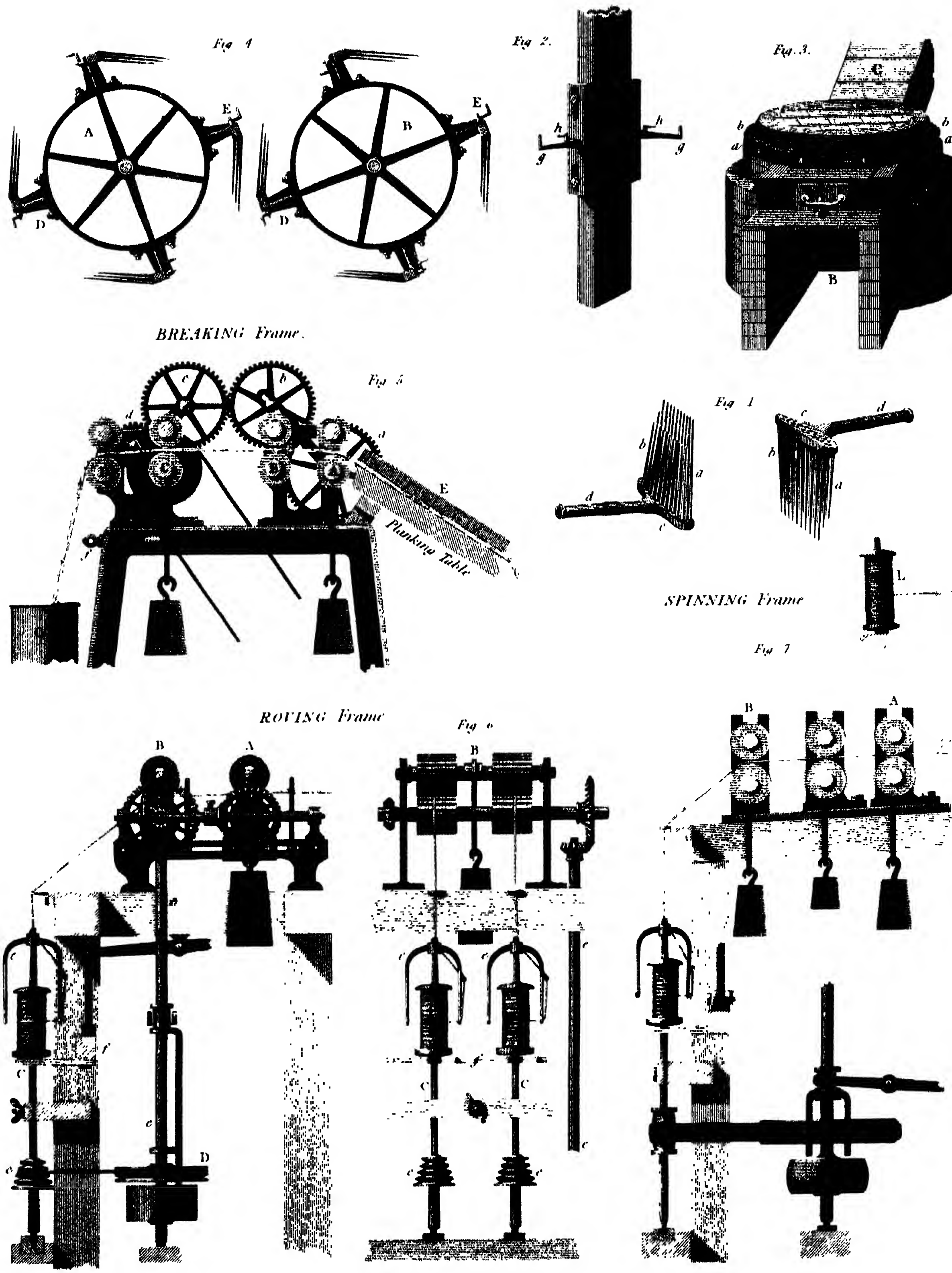
Reeling.—The bobbins of the ſpinning-frame are placed in a row upon wires before a long horizontal reel, and the threads from 20 bobbins are wound off together. The reel is exactly a yard in circumference, and when it has wound off 80 turns, it rings a bell; the motion of the reel is then ſtopped, and a thread is paſſed round the 80 turns or folds which each thread has made: the reeling is then continued till another 80 yards is wound off, which is alſo ſeparated by interweaving the ſame thread; each of theſe ſeparate parcels is called a ley, and when ſeven ſuch leys are reeled, it is called a hank, which contains 560 yards. When this quantity is reeled off, the ends of the binding thread are tied together, to bind each hank faſt, and one of the rails of the reel is ſtruck to looſen the hanks, and they are drawn off at the end of the reel. Theſe hanks are next hung upon a hook, and twiſted up hard by a ſtick, then doubled, and the two parts twiſted together, to make a firm bundle. In this ſtate, the hanks are weighed by a ſmall index-machine, which denotes what number of the hanks will weigh a pound, and they are ſorted accordingly into different parcels. It is by this means that the number of the worſted is aſcertained as the denomination for its fineneſs: thus No. 24. means that 24 hanks, each containing 560 yards, will weigh a pound, and ſo on.

This denomination is different from that uſed for cotton, becauſe the hank of cotton contains 840 yards inſtead of 560; but in ſome places, the worſted hank is made of the ſame length as the cotton.

To pack up the worſted for market, the proper number of hanks are collected to make a pound, according to the number which has been aſcertained; theſe are weighed as a proof of the correctneſs of the ſorting, then tied up in bundles of one pound each, and four of theſe bundles are again tied together. Then 60 ſuch bundles are packed up in a ſheet, making a bale of 240 pounds, ready for market.

From this account of the proceſſes of worſted ſpinning, it will be ſeen that they are very ſimilar to thoſe of cotton-ſpinning, after the firſt preparation of the wool by combing inſtead of carding.

WORSTED-*Cord*, in *Sheep-Farming*, is a ſort of cord which is ſometimes uſed for tying round the necks of ſheep affected with the ſcab, after it has been well ſmeared over with the common mercurial ointment of the ſhops, in order to cure them of that diſeaſe. See SCAB.



J. Farey del. Published as the Act directs, 1819, by Longman, Hurst, Rees, Orme & Brown, Paternoster Row. W Lowry

Yufts

YUFTS, or *Russia Leather*, as it is called in England, are the chief products of the tanneries in Russia; and the principal places in which they are prepared, next to Moscow and Petersburg, are, Arsamas, Kostroma, Yaroslaf, Pscove, Kazan, Vologda, Nishney-Novgorod, Vladimir, Ekatarinenburg, &c. Mr. Tooke has described the process by which they are prepared:—The raw ox-hides are first laid in running water, or in large tan-pits full of water dug in the earth for that purpose, to soak for a whole week; but in summer not so long. During this time they are daily taken out of the water, and scraped at a scraping-bench, or wooden horse. Having now been duly steeped, they are put into a ley, thus prepared: In other vats, likewise dug in the ground, and under cover, they mix two parts of good ashes with one part of unslacked lime, in boiling water, and sink the wet hides in this ley on a grating, which being suspended by cords, can be raised or let down at pleasure. In this vat the hides are laid again for about a week, though in warm weather less, in cold perhaps even longer. The sign that they have lain long enough in the ley is, that the hair can without difficulty be rubbed off with the hand, so that none remains. If the hides, after the expiration of a week, are not in that condition, fresh ashes are put into the ley, and the skin sunk in it. But if at length the hair be sufficiently loose, the hides are entirely taken out of the ley, and all the hair scraped off on a stretching-block, by means of blunt iron scrapers with two handles. The hair is washed clean, and sold for domestic uses. The hides, thoroughly cleansed from hair, are suspended in vats of clean water on a running stream, where they remain three days, diligently turning them to and fro, in order to purge them from the ashes and ley; afterwards they are hung up, and left to drain. The hides must now be scraped on the flesh side. To this end they employ either the aforesaid scraping-iron, or others sharper in various degrees. After this treatment, the hides are trampled. But calves-hides have another sort of preparation, which the yuft-tanners, in the interior towns of the empire, who mostly practise it, call rakscha. This preparation is performed with the white excrement of dogs dried, which is dissolved in boiling water, and to a hundred hides about four vedros full of excrement is the rule. If here the right proportion with the water be not found, the hides corrupt in this slime, the object whereof seems to be the complete freeing of the skin from the salts that adhere to it from the ley. The hides are left to lie twice twenty-four hours. With this is stirred a sour gruel of oatmeal with warm water, and to three osmics, or eighths of a chetverik, three or four vedros of dregs of the common quas, which the people make of meal and a small portion of malt, put in the thin gruel, that it may quickly sour with the hides. To ten hides, the tanners usually reckon forty pounds of meal.

After the hides have soured, which is done in large vats, they are laid in other vats, and well steeped for two or three days in a strong tan-juice, sok, thoroughly boiled from good bark. When this is done they are brought straight to the tan. In the tan-pits, in which often some hundreds of hides are lying, is poured half water and half tan, or water boiled with tan, and a grating is hung in with cords, having one hide after the other spread upon it, thick strewed with good fine-pounded tan, and the grating constantly let deeper into the pit, till it be nearly full; yet so that the tan-liquor is always above the hides, which are then again sprinkled over with tan. In this tan the hides continue to lie a week; those of full-grown animals longer. On being taken out, they are washed and trampled on, which two workmen in a summer's day can perform with three hundred hides. The next day they are laid, in the manner above-described, in fresh tan. Thus they generally get four times successively fresh tan, and are every time rinsed clean. In the last tan they lie three weeks, or longer, are then finally washed, hung up, and, when they have tolerably drained, delivered to those workmen whose business it is, in particular workshops, to dye, dress, and wax the yufts, and to deliver the goods finished. It is to be observed, that the Russian yuft-tanners seldom use oak-tan, and never willingly. The choicest and best tan is that of the tschernotal, as they call it, or the black willow; and also the young bark peeled off from other shrubby willows, which are collected by the boors, dried in bundles, and brought in cart-loads to market. To ten hides, the tanners compute one and a half fathom of these bundles of willow-

bark, as they are laid one upon another for ſale, through all the tans. It muſt not, however, be imagined that the excellence of the Ruſſian yufts depends on this; for in Siberia, where are no oaks, and but few willows of any ſize, they tan yufts with only birch-bark, which are not much worſe than the Ruſſian. The bark is made ſmall by either ordinary tan-mills, turned by horſes or by water; or the tanner himſelf, in many towns where there are no mills, cauſes it, at unneceſſary expence and labour, to be pounded in wooden mortars, or excavated blocks, with peſtles, almoſt like thoſe in the tan-mills, by day-labourers.

The dyeing of the yufts is performed in two ways, and of two colours. The commoneſt and moſt natural cuſtom of giving the colour to the hides is, by ſewing them together in pairs, the hair ſide inwards, while they are yet moiſt, round the edges, with ruſhes or ſtripes of bark, thus forming them into a bag or ſack; into this ſack the colour is put, the ſack well ſhook, and the ſuperfluous dye let to run out, whereupon the ſkins are dried. From this method of dyeing them, it ſeems to proceed that the yufts are called and taken by pairs. The other proceſs, whereby much trouble, time, and colour are ſaved, and the edges of the ſkin entirely preſerved, is the following: Each ſkin is hung upon a horſe over a long trough, ſo that the hair ſide, which muſt be ſtained, appears outwards, pouring the dye upon it out of the dye-kettle, till the whole ſkin is dyed. The two colours given to the yufts are red and black. The red dye is thus prepared: Pound braſil-wood (ſandal) in the pounding-mill, or with hand-peſtles, as fine as the tan, and boil it in kettles. Previous to the dyeing, ſteep the ſkins in alum-water. It is calculated, that to each ſmall yuft-ſkin a half, and to a large one a whole pound of logwood is put. But the latter are moſtly coloured black. To a hundred yufts to be dyed red, four pounds of alum is ſufficient. For dyeing black the braſil-wood is likewiſe uſed; but in the red dye, to a hundred ſkins three pounds of good iron vitriol is diſſolved. After the firſt tincture the ſkins are dried, and afterwards on tables done over again with the ſame dye and rolled up, that they may thoroughly imbibe the dye. For heightening the colour this tincture is ſometimes thrice repeated. When the ſkins are now tolerably dried, by hanging, that the colour may not fade, with the fleſh ſide outwards, the yufts, ſtill ſomewhat moiſt, are ſmeared over on tables that have ledges. There was a time when it was commanded by authority to uſe nothing but dolphin and ſeal-blubber for ſmearing them; but by that the yufts are harſher, and have not that yuft ſmell, which foreigners prize ſo much, unleſs the birch-tar, deggot, prepared in Ruſſia, at leaſt be mixed with it. At preſent this birch-tar alone is uſed for ſmearing. This done, the ſkins are cleanſed from any impurities that may remain, and are ſent to the dreſſing-houſe, where ſkilful workmen ſcrape them firſt with ſcraping-irons, having two handles, with the edge croſs-wiſe on a ſtretching-bench, that a ſoft thin leather remains with a clear gloſſy ſurface, free from all impurities. Other workmen then take the clean-ſcraped yufts on large clean tables, ſprinkle them on the fleſh ſide with a gentle ſhower of freſh water from their mouths, and lay them ſlightly rolled up to moiſten. This done, the ſkins are taken ſeparately one after another, folded together, and worked and calendered in all directions, to make them ſoft and pliant. They are then curried with a kind of wooden curry-comb, with ſharp irons fixed in leathers, like a card for carding wool, the ſkin being folded with the hair ſide outwards, by which the whole ſurface of the yufts acquire the croſs-ſtrokes or trellis-like marks they are always ſeen to have. Some work the ſkins with the hands firſt dry, not ſprinkling them till they are mangled with the card. Laſtly, thoſe ſkins which are too harſh and ſtiff to the feeling, are more or leſs ſprinkled with linſeed-oil, and thus are ready for the merchant.

In this connection we ſhall introduce from the ſame author an account of the Ruſſian method of preparing and dyeing their ſaffian, maroquin, or Morocco leather, which are dyed at Aſtrachan of three colours, red, yellow, and black. The treatment of the red ſaffians, which are the moſt famous, is uſually as follows:—The raw hides are firſt laid in large vats, and have river water poured upon them, in which they are left to ſoak for three or four times twenty-four hours. They are then taken out, the water is drained and ſqueezed from each ſkin, and are ſcraped one by one on the ſtretching-bank with ſcraping-irons, uraki, quite gently on the fleſh ſide, in order to take away the groſſer impurities, but principally for opening the ſkin, and to qualify it for the enſuing operation.

They now proceed to make the hair fall clean off, chiefly by the application of lime. To a hundred hides is ſtirred in about half a buſhel of unſlaked lime in vats with river water, and the hides are laid in ſo as that the lime may as much as poſſible be equally diſtributed over all of them. The Aſtrachan Tartars let the hides lie in this lime-pit frequently three weeks; but it is well known, that their ſaffians are ſo harſh and liable to crack, and even ſcorched by it, that they are fit for nothing, and can only impoſe upon an inexperienced purchaſer. They then take out ſkins, waſh them, and carefully ſcrape off the hair, now become looſe, with wooden ſcrapers. It often happens, that the hair is not perfectly looſened by the firſt lime-ley, but that many tender ſtubbles and ſmall hairs are left remaining. In this caſe, the hides muſt be put into freſh lime-ley, and be left perhaps two weeks in it; the hair then comes off, and the hair ſide of the ſkin gets a green and very white appearance, but the ſubſtance is then alſo very ſoft, and the ſaffians, by this corroſion of the lime, are very little durable in compariſon of other kinds of leather.

The method now for taking the lime again out of the hides, is the ſecond treatment with dog-excrement, or white gentian, which is carefully collected for this purpoſe. This excrement, which is indiſpenſably neceſſary, is pounded, put into a narrow not very large vat, warm water poured upon it, the maſs thoroughly ſtirred, and the cleanſed hides are put with it into another vat, ſo as that the diſſolved album grecum is ſpread and inſinuated over and between every ſkin. In theſe ingredients, the ſkins muſt lie only twenty-four hours, or if the quantity of album grecum prove not rich, ſomewhat longer. The proportion here to be obſerved cannot be accurately aſcertained; for the ſaffian-makers are guided generally by eye-meaſure, and obſerve only that the water be very thick and turbid, and conſequently acrid enough. The hides come out of this corroſive much ſofter and thinner than they were, and are now freed from the force of the lime; but no time muſt be loſt in endeavouring to extract the corroſive likewiſe, that the hide may not be even more ruined by it than by the lime. They are generally very careful that the hides lie not too long in this corroſive, which they judge of by their eye from the pliancy and ſuppleneſs of them. As ſoon as the ſkins are lifted out, the unclean moiſture is carefully and forcibly preſſed out, and they are laid without loſs of time in a vat, wherein wheat-bran is ſtirred to a tolerably thick gruel with warm water; in this they lie again about thrice twenty-four hours, whereby all the former defects are completely remedied, and the ſubſtance of the

ſkin is ſofter and mellow. All theſe particulars are in ſome meaſure of no other ſervice than to bring off the hair thoroughly clean from the ſkin.

Now follows the proper preparation of the ſkins taken out of the wheat-bran. This is done chiefly by honey. To eighty hides they take about twenty-five pounds of raw honey, boil it in a kettle, pour as much water to it as is neceſſary for giving it a due conſiſtence, and ſtir it for a pretty long time boiling on the fire. They then let the kettle cool, till they can but juſt bear the hand in it, and then pour the ſtill hot honey-water on the hides lying ſingly in little trays, by ladle-fulls, till they have thoroughly imbibed the honey-water. When all the ſkins are duly drenched, they are thrown into a dry vat all together, laying at top a board with weights upon it, and covering the whole vat with felt, carpets, or furs, that the vapour during the fermentation may not eſcape; and in this manner, the ſkins muſt ferment once more thrice twenty-four hours. By this means they acquire the grain. From the honey-vat they are rinſed clean in luke-warm water, wrung as dry as poſſible, and ſteeped immediately in a moderately ſtrong pickle or brine made of common ſalt, in which they muſt be left five or ſix days. This time being elapſed, the ſkins are taken out of the pickle, and hung upon clean poles, that the brine may drain out, as it would be thought injurious to ſqueeze it out with the hands. This done, the ſkins have received their whole preparation, and may now be dyed red, but not yellow; becauſe for the yellow ſaffians, as was ſaid before, the preparation is of another kind.

For giving the red ſaffians the colour, nothing is uſed but cochineal, or, as the Tartars call it, kirmiſs, and that in the following method: Firſt, they boil a quantity of the herb ſalſola ericoides, by the Tartars called tſchagan, plentifully growing on the arid Aſtrachan ſalt-ſteppes. To about four Ruſſian vedros of water is put of this dried herb ſomewhat leſs than a pound, and it is ſet to boil for a whole hour, whereby the water acquires a dark greeniſh colour, but betrays no acrimony to the taſte. The ſaffian-maker only takes care that the water be not too deeply tinctured, and that when dropped on the thumb-nail ſhews only a ſcarce perceptible green; and in caſe it have adopted too many particles of the colour, it is drawn off, and freſh water put, in which the herb muſt boil again, till the decoction has received the due degree of ſaturation. The herb is then with a ſcoop taken clean out of the kettle, and then the previouſly nicely powdered cochineal thrown into a kettle of four Ruſſian vedros to about half a pound, well ſtirred, and freſh fire added, in which great attention muſt be paid, that the red ſcum, which ariſes from boiling, does not boil over, therefore conſtantly ſome is taken and again poured in, in order by this refrigeration to prevent the over-boiling, and to allay the foam. After boiling for about an hour and a half, the water has obtained a ſtrong tincture; but as much of it is boiled away, the kettle is filled up again with the remaining decoction of the herb tſchagan, and the thus attenuated colour boiled afreſh, till it is ſeen that the cochineal is perfectly diſſolved, and the colour become thoroughly bright. Upon this, to the whole kettle is put about two lote of pounded and burnt alum into the dye, with which it is to boil about a quarter of an hour, and then the fire is taken from under the kettle, leaving only ſome hot embers, that the dye may retain as much heat as the hand can but juſt bear. This done, the ſkins prepared for dyeing are taken in hand, the dye poured by ladles into trays, one ſkin folded together after another, with the hair ſide outwards, and then are worked in their portion of dye ſo long, till they have uniformly abſorbed all the dyeing particles, and only ſomewhat of a pale moiſture remains. The leathers being thus for the firſt time ſtained are quickly ſqueezed out, hung up ſingly acroſs poles, and when they are all done, they are directly taken for the ſecond time, and imbued in the ſame manner with dye, and this treatment is repeated for the third and the fourth time; ſo that each ſkin gets four ladles of the dye. From the fourth dye the ſkins are no more preſſed out, but hung up entirely wet, to be ventilated, upon poles.

After the dye, the ſkins are once more curried with the leaves of the tan-tree, which the Armenians call belgè. The cruſhed or pounded dry leaves, which the Aſtrachan ſaffian-makers get from the Terek, are ſtirred in broad troughs to a thick gruel with river water, and the coloured ſkins laid in it, between each of them, leaving a ſufficiency of the leaf-ooze; the tanner then goes barefoot into the troughs upon the ſkins lying on one another. In this tan, or quas, as the workmen call it, the ſaffians lie eight days and nights, adding freſh tan every other day; ſo that four tans are neceſſary.

Here it muſt be obſerved, that ſome Armenians who prepare ſaffians, for enhancing the quality of the red colour of their ſaffians, to half a pound of cochineal add two lote, or rather more of ſorrel, (or lutor, or loter, as they call it,) in the dye-kettle, but it is uſually omitted in Aſtrachan, on account of its high price; for which reaſon the Aſtrachan ſaffians are excelled by the Turkiſh in beauty of colour. Secondly, it is to be known, that inſtead of the leaves of the tan-tree, bruiſed nut-galls are held to be ſtill more ſerviceable for giving the ſaffians the tan. By this means, the colour is ſo durable as never to paſs away but with the leather; whereas the ſaffians prepared with the tan-tree begin ſoon to be diſcoloured. But the nut-galls are likewiſe too dear in Aſtrachan to be cuſtomarily uſed by the ſaffian-makers. The Kazan Tartars colour their ſaffians with red wood, and tan them with the ſhrub uva urſi, but it makes the worſt ſaffians of all, as they preſently fade.

When the ſaffians are lifted out of the tan, ſtill the laſt work remains. They are firſt left ſome time in the air to dry, they are afterwards ſcraped on the ſtretch-bank with ſharp ſcrapers on the fleſh ſide, quite ſmooth and clean, then waſhed in running water, each ſkin duly ſtretched with pegs all round the edges, and thus left till they are dry.

The ſkins muſt now be ſmoothed on the hair ſide with a wooden inſtrument for that purpoſe; and laſtly, they are laid on a thick felt, where, with an iron heckle that has blunt points, thoſe little pittings, which the ſaffians are generally ſeen to have, are impreſſed on the ſame ſide. And thus they are ready for ſale, without being ſmeared with linſeed-oil, as is mentioned in Gmelin's travels, which would infallibly ſpoil them.

The yellow ſaffians are little made in Aſtrachan, as the demand for them is much leſs, and there are but few ſaffian-makers who know much of the matter. The dye which they make uſe of for this purpoſe is of the berries of a ſort of rhamnus (perhaps lycioides), which are brought from Perſia under the name of uloſcharr, and uſually bought for ſix to nine rubles the pood. The Kazan Tartars colour their ordinary yellow ſaffians with the flowers of the yellow camomile, which they gather under the name ſare tſchetſchiak, *i. e.* yellow-flower.

In preparing the yellow ſaffians, they obſerve in Aſtrachan the following difference of treatment: 1. They make no uſe whatever of honey in the preparation. 2. They

never at all put the hides into the ſalt brine. 3. Inſtead of the honey-preparation and the pickling, they lay the hides before the dyeing, in the foregoing manner, in the tan of the leaves of the kitzhar tan-tree, leaving them in it eight days. 4. For preparing the dye, they have no need of the herb tſchagan, but the berries alone are boiled in clear water, of which to four Ruſſian vedros of water about ten pounds are requiſite, and heighten the colour afterwards with three lotes of alum to every pound of berries. The dyeing is performed in the ſame manner as has been related with the red, and after the dyeing there is no need to lay the ſaffians in the tan, as having before received it. Nothing more is neceſſary than to ſcrape them clean, to work them thoroughly, to poliſh and to ornament them. The yellow ſaffians uſually are ſold at one ruble twenty kopeeks; but the red at ſomewhat more, on account of the dearneſs of the dye, generally one ruble eighty kopeeks.

Zinc

ZINC, in *Chemiſtry*, the name of a metal, in Latin *zincum*. The ancients do not appear to have been acquainted with this metal. *Cadmia* was the name by which they ſeem to have known one of its ores, which was ſo called from Cadmus, who, it is ſaid, taught the Greeks how to form braſs by its means. It is firſt mentioned by Albertus Magnus, but it is doubtful if he had ever ſeen it. The word *zinc* firſt occurs in the writings of Paracelſus. This metal has been alſo called *ſpelter*.

Zinc has never been found in Europe in a ſtate of purity, and chemiſts were late in diſcovering a method of extracting it from its ores. Henkel ſeems to have been one of the firſt who effected this about the year 1720, and he was ſoon followed by others. Zinc is of a brilliant white colour, with a ſhade of blue, and ſeems to be compoſed of a number of thin plates adhering together. It imparts a perceptible ſmell and colour to the ſkin when rubbed by it for ſome time; hence it is rather ſoft. Its ſpecific gravity is ſaid to vary from 6.86 to 7.1, the lighteſt being eſteemed the pureſt. When hammered, its ſpecific gravity becomes as high as 7.19.

This metal is by no means ſo malleable as copper, lead, or tin; it is not however brittle. It yields, and becomes ſomewhat flatter, when ſtruck with a hammer. When heated a little above 212°, it has the remarkable property of becoming very malleable, and in this ſtate may be reduced into very thin plates, either by hammering or rolling. When heated to about 400°, it becomes ſo brittle that it may be reduced to powder in a mortar.

Zinc may be drawn into wire. According to Muſchenbroeck its tenacity is ſuch, that a wire of $\frac{1}{10}$th of an inch in diameter is capable of ſupporting a weight of about 26 lbs.

Zinc melts at a temperature of about 680°, according to Dr. Black. If the heat be increaſed it evaporates, and may be eaſily diſtilled over in cloſe veſſels: upon this property of zinc, Von Swab's method of extracting it from its ore was founded. When allowed to cool ſlowly, this metal cryſtallizes beautifully in ſmall bundles of quadrangular priſms diſpoſed in all directions, which, if expoſed to the air while hot, aſſumes a blue changeable colour.

When expoſed to the air, zinc ſoon tarniſhes, but it ſcarcely undergoes any other change. When kept under water, its ſurface becomes black, the water is decompoſed, hydrogen is emitted, and the oxygen combines with the metal. If heat be applied, theſe changes go on more rapidly; and if the ſteam of water be made to paſs over zinc at a high temperature, it is very rapidly decompoſed.

When this metal is kept melted in open veſſels, it ſoon becomes covered with a grey pellicle of oxyd. If the heat be very ſtrong it takes fire, and burns with a brilliant white flame, and at the ſame time emits a great quantity of very light white flakes. This is merely the oxyd of zinc. It was well known to the ancients, and received from them many whimſical names, ſuch as *pompholyx*, &c. Among the alchymiſts it was known by the names of *nihil album*, *lana philoſophica*, *flowers of zinc*, &c.

Zinc appears to combine with only one proportion of oxygen, which has been ſtated by different chemiſts to vary from 24.16 to 25 of oxygen to 100 of the metal. According to the firſt of theſe determinations, the weight of the atom of zinc will be 41.39; according to the ſecond 40. Dr. Thomſon has decided upon 41.25 as the moſt probable weight of the atom.

Zinc combines readily with chlorine, and forms a chloride of zinc. It may be prepared by diſſolving zinc in muriatic acid, or by expoſing the metal to the gas, when the two combine by a ſpecies of combuſtion. The chloride may be alſo obtained by diſtilling zinc-filings with the oxy-muriate of mercury, or *corroſive ſublimate*; and thus obtained, it was formerly denominated the *butter* of zinc. When thus prepared, it ſublimes on the application of heat, and cryſtallizes in needles; but according to Dr. Davy, when the common muriate is heated in a glaſs tube, it does not ſublime even at a red heat, but remains in a ſtate of fuſion. Expoſed to the air, it ſoon deliqueſces. According to Dr. J. Davy's analyſis, it is compoſed of

Chlorine - - - -	100
Zinc - - - - -	100

But if we ſuppoſe it to be compoſed of an atom of zinc

and an atom of chlorine, and the atom of zinc to weigh as above, its constituents should be

Chlorine - - - -	100
Zinc - - - - -	91.6

Zinc readily combines with iodine by heat. The compound, or *iodide*, is white. It is volatile, and crystallizes in fine quadrangular prisms. It deliquesces in the air, and is very soluble in water. The solution is colourless, and does not crystallize. Gay Lussac has shewn, that this compound consists of one atom iodine, and one atom zinc, or by weight of

Iodine - - - -	100
Zinc - - - - -	26.52

No compound of zinc with fluorine is at present known. Zinc does not combine with azote nor hydrogen; nor are we acquainted with any compound of this metal with boron and silicon.

Zinc may be combined with phosphorus by dropping small bits of phosphorus into it while in a state of fusion. Phosphuret of zinc is of a white colour, and possesses a metallic lustre, which more resembles lead than zinc. It is somewhat malleable. It emits the odour of phosphorus when filed or hammered, and if exposed to a strong heat it burns like zinc. Phosphorus also appears to combine with the oxyd of zinc, and to form a peculiar compound.

Sulphur cannot be combined artificially with zinc; but if melted with the oxyd of zinc a peculiar compound is formed. A similar compound is formed when sulphuretted hydrogen in combination with an alkali is dropped into a solution of zinc. It is at first white, but becomes darker on drying. Dr. Thomson considers this compound as a sulphuret of zinc. Mr. E. Davy ascertained, that when the vapour of sulphur is passed over zinc in fusion a yellowish compound is obtained, similar in appearance to blende.

One of the most common ores of zinc is *blende*, described below, and which is a sulphuret of zinc, composed, according to Dr. Thomson's experiments, of

Zinc - - - -	100
Sulphur - - - -	48.84

Hence he considers it as a compound of one atom zinc, and one atom sulphur.

The alloys of zinc and the metals of the fixed alkalies are speedily decomposed by exposure to the air or immersion in water. We are not acquainted with the alloys of zinc and the metallic bases of the alkaline earths.

Zinc may be combined with arsenic by distilling a mixture of it and arsenious acid. With iron, zinc combines with difficulty; the alloy when formed, according to Lewis, is hard, somewhat malleable, and of a white colour, like silver. Malouin has shewn, that zinc may be used instead of tin for covering iron plates; a circumstance which demonstrates an affinity between the two metals.

Zinc does not appear capable of combining with nickel or cobalt by fusion. The alloys of zinc with manganese, cerium, and uranium, are unknown.

For the other alloys of zinc, see the different metals; particularly for the most important of them or brass, see BRASS and COPPER.

Salts of Zinc.—Almost all the acids act with energy on zinc, in consequence of its powerful affinity for oxygen. The salts of zinc, therefore, are very easily formed, and on account of their being but one oxyd of zinc are not much liable to variation.

Nitrate of Zinc.—The nitric acid attacks zinc with such energy, that it is commonly necessary to moderate its action by diluting it with water. Even then much heat is evolved, and a strong effervescence is produced by the escape of nitrous oxyd gas. The solution is transparent and colourless, very caustic, and yields by evaporation flat, striated, tetrahedral prisms, terminated by four-sided pyramids. These crystals attract moisture on exposure to the air, and are soluble in water and alcohol. When heated they melt, and if thrown on burning coals, detonate with a red flame.

Carbonate of Zinc.—*Calamine*, one of the ores of zinc, is a native carbonate of zinc, as described below. This salt usually exists in the form of a white powder, and may be obtained by precipitating zinc from its solution in acids by an alkaline carbonate.

Phosphate of Zinc.—The phosphoric acid unites in two proportions with the oxyd of zinc. The neutral phosphate is a tasteless white powder insoluble in water. The biphosphate is soluble in water, if not exposed to too great a heat. It does not crystallize, and is strongly acid.

Sulphate of Zinc.—Concentrated sulphuric acid scarcely acts upon zinc without the assistance of heat; but when diluted it acts upon the metal very strongly, and hydrogen gas is given out in abundance. In this case, the water is decomposed, its oxygen combines with the metal, while its hydrogen escapes. The solution, when concentrated, yields crystals in abundance.

This salt, formerly known under the name of *white vitriol*, was discovered in Germany, about the middle of the 16th century. When quite pure, it is perfectly white. The form of its crystals is that of flat quadrangular prisms, terminated by four-sided pyramids. At a temperature of 60°, it dissolves in about 1.4 times its weight of water. In boiling water, it dissolves in any quantity whatever. The constituents of this salt are,

1 Atom of sulphuric acid - -	31.74
1 Atom of zinc - - -	32.54
5 Atoms of water - - -	35.72
	100.00

When heated, the crystals part with their water, and if the heat be strong, the whole of the acid likewise separates, and leaves the oxyd of zinc in a state of purity. See VITRIOL, *White*.

Muriate of Zinc.—See *Chloride of Zinc, supra.*

Sulphite of Zinc.—This salt exists in the form of crystals, soluble in water, but insoluble in alcohol. On exposure to the air, they are soon converted into the sulphate of zinc. Fourcroy and Vauquelin describe a *hypo-sulphite* of zinc, which assumes the form of four-sided prisms, terminated by four-sided pyramids. They are soluble in water and alcohol.

Borate of Zinc is a white insoluble powder. It may be formed by pouring borate of soda into the nitrate or muriate of zinc.

Arseniate of Zinc is a white insoluble powder, and may be formed by mixing solutions of the alkaline arseniates with the sulphate of zinc.

Acetate of Zinc.—This salt exists in the form of rhomboidal or hexagonal plates of a talky appearance, and is not very soluble in water. Solutions of this salt form an excellent external application to inflammations.

Oxalate of Zinc.—This salt is a white powder, little soluble

in water, and may be formed readily by double decomposition.

Tartrate and Citrate of Zinc. — Both these salts exist usually in the form of powders, and are but little soluble in water. They may be procured, like the oxalate, by double decomposition.

The other salts of zinc are of very little importance or interest, and do not therefore merit to be enumerated here. The salts of zinc may be distinguished in general by their forming colourless solutions in water, by their yielding white precipitates with prussiate of potash, sulphuretted hydrogen, and the alkalies, and by the characteristic circumstance that zinc is not precipitated in the metallic state by any other metal.

Uses of Zinc and its Compounds.—Neither this metal nor its compounds, if we except *brass*, are much employed in the arts nor in medicine. A chief use of zinc is in the formation of galvanic apparatus, and in electrical experiments. (See GALVANISM and ELECTRICITY.) As it is not a poisonous metal, it has been recommended instead of tin and lead for domestic purposes; but the ease with which it is oxydized makes it very unfit for all sorts of culinary apparatus.

The strong affinity of zinc for oxygen renders it of great use as a chemical agent for precipitating other metals from a state of solution in the metallic state. The oxyd of zinc is used in medicine, both internally as a tonic, and externally mixed with hog's-lard as an ointment. The native carbonate is also used in the same manner as an external application. See UNGUENTUM *Calaminæ*, and UNGUENTUM *Zinci*.

The *sulphate* and the *acetate* are the only salts of zinc used in medicine; for the properties of which, see above.

ZINC, *Ores of*, in *Mineralogy*. The ores of zinc are generally associated with lead-ores, and exist abundantly in various parts of England; particularly in veins in the mountain lime-stone of Derbyshire, Durham, Cumberland, Yorkshire, Somersetshire, and North Wales. The ores of zinc are either oxyds, carbonates, or sulphurets of zinc, and are principally known as calamine or blende. There is an ore of zinc hitherto found only in North America, called by Dr. Bruce red zinc-ore; it occurs in several of the iron-mines in Sussex county, New Jersey.

Red Zinc Ore is of a blood-red or aurora-red colour: it occurs massive and disseminated. The fresh fracture is shining, but becomes dull after long exposure to the air, and is covered with a pearly crust; the principal fracture presents a foliated structure; the cross fracture is conchoidal. It is opaque or translucent on the edges; it yields a brownish-yellow or orange streak; it is brittle. The specific gravity is 6.22. It is infusible without addition by the blow-pipe, but melts into a transparent yellow bead with borax. When pounded and mixed with potash, and exposed to heat, it melts into an emerald-green mass, which, on solution in water, yields the same colour; but on the addition of the mineral acids is immediately changed to rose-red. This ore is soluble in the mineral acids. Its constituent parts are,

Zinc - - - - -	76
Oxygen - - - - -	16
Oxyds of manganese and iron	8
	100

Bruce's American Mineralogical Journal, p. 69.

According to Dr. Bruce, this ore possesses advantages in the manufacture of brass over those generally used; for without any previous preparation, it affords with copper brass of the very finest quality, possessing a high degree of malleability, and suited for the most delicate workmanship. Red zinc-ore is characterized and distinguished from red silver-ore and red lead-ore by its infusibility; the latter melting into a blackish slag before the blow-pipe. Red orpiment, with which it might be confounded, is distinguished from red zinc-ore by its volatility, and the garlic smell which it yields. This ore of zinc has greater specific gravity than red copper-ore, and its solution in acids is colourless; but those of red copper are green. Calamine is divided by some mineralogists into four kinds, sparry calamine, compact calamine, earthy calamine, and electric calamine.

Sparry Calamine: Zinc Carbonaté, Haüy.—Its colours are greyish and yellowish-white, and sometimes green and reddish-brown. It occurs massive, botryoidal, cellular, stalactitic, and crystallized, in acute and obtuse rhomboids, and in longish quadrilateral tables: the crystals are small. The lustre of sparry calamine is between resinous and vitreous. The structure is imperfectly lamellar, and sometimes radiated. It is translucent, or more or less transparent; it yields easily to the knife. The specific gravity is 4.3. It is infusible before the blow-pipe, and loses about 34 *per cent.* by ignition. With muriatic acid it effervesces, and is dissolved. According to Smithson, the constituent parts of this ore from Derbyshire are,

Oxyd of zinc - -	65.2
Carbonic acid - -	34.8
	100.

From Somersetshire,

Oxyd of zinc - -	64.8
Carbonic acid - -	35.2
	100.

Compact Calamine: Zinc Carbonaté, Haüy.—Its colours are, greyish, greenish, or yellowish, and often brown, from an intermixture with iron. It occurs massive, botryoidal, disseminated, stalactitical, reniform, and mamillated: it has a dull, feebly glistening, resinous lustre. The fracture is uneven and coarse-grained, or splintery, and sometimes even a flatty conchoidal. It sometimes occurs in concentric lamellar concretions: it is opaque. Its chemical characters and constituent parts are the same as of the sparry calamine, these minerals being only varieties differing in form from each other.

Earthy Calamine: Zinc Carbonaté, Haüy.—It is of a greyish or yellowish-white colour, sometimes snow-white; externally it is frequently covered with a tint of yellowish-brown. It occurs massive, and coating other minerals; it is opaque, and has an earthy fracture; it yields to the nail, and adheres to the tongue. The specific gravity is 3.358. According to Smithson, the constituent parts are,

Oxyd of zinc - -	71.4
Carbonic acid - -	13.5
Water - - -	15.1
	100.

Electric Calamine: Zinc Oxydé, Haüy.—Its prevailing colours are, greyish, blueish, or yellowish-white; externally it is sometimes brownish or blackish. It occurs crystallized, mamillated, botryoidal, stalactitical, and massive. The crystals are six-sided prisms, with dehedral summits, or acute

octahedrons; sometimes truncated on the summits. The crystals are small, and either solitary, or radiating in groups, like zeolite. The lustre is shining, glistening, and vitreous: the structure is imperfectly lamellar, or divergingly fibrous. It is sometimes opaque, and sometimes translucent or transparent: it yields to the knife, but is much harder than common calamine. The specific gravity is 3.4. When gently heated it is strongly electric; it is infusible, and loses about 12 *per cent.* by ignition. It is soluble in muriatic acid with effervescence: the solution gelatinizes on cooling. According to Klaproth, its constituent parts are,

Oxyd of zinc - - - -	66
Silex - - - - -	33
	99

According to Smithson,

Oxyd of zinc - - -	68.3
Silex - - - - -	25.
Water - - - - -	4.4
	97.7

Calamine sometimes occurs in what are called supposititious crystals, as if it had been moulded over crystals of other minerals, and the internal crystal had disappeared. In Derbyshire, the working miners are of opinion, that the calamine destroys the lead-ores when they occur together; or, as they express it, the calamine eats up the lead. That some process of decomposition or change takes place where these ores are associated there can be no doubt; but by what means this is effected we are at present ignorant. See VEINS, *Metallic.*

Calamine, commonly called lapis calaminaris, when cleaned and roasted, is used for the fabrication of brass, forming a compound with copper. (See BRASS.) Its uses in the making of brass is of very high antiquity, being mentioned by Aristotle.

Calamine is also the most valuable ore from which metallic zinc is extracted.

The uses of calamine were not known in England before the reign of queen Elizabeth, and even so late as the year 1700 it was commonly carried out of the kingdom as ballast by the ships which traded to Holland. The calamine raised in Derbyshire about the year 1780 amounted to 1500 tons. Sixty years before that time the quantity got did not exceed 40 tons, the greater part being thrown away through ignorance of its nature and value.

The dressing of calamine consists principally in picking out all the pieces of lead-ore, lime-stone, iron-stone, heavy spar, and other minerals mixed with it in the mine. The picked calamine is then calcined in proper furnaces, and loses by calcination between a third and fourth part of its weight, which is the carbonic acid. In great works, where calamine is prepared for the brass-makers, after its calcination, it is carefully picked again, the accidental ingredients being rendered more discernible by the action of fire. It is afterwards ground to a fine powder, and washed in a gentle rill of water, to free it from earthy particles with which it may be intermixed; for these being lighter are carried off by the water: it is then made up for sale.

A ton of the crude Derbyshire calamine, as dug from the mine, is reduced, by the various processes it undergoes before it becomes fit for use, to about twelve hundred weight. Part of the zinc is lost in calcination, particularly if too strong a fire be made: this is evident by the flame visible over the furnace. It would be practicable to use calamine without calcining it, for the carbonic acid would be expelled by the heat applied in making brass; but then there would be seven or eight hundred weight put into the brass pots which would be of no use in the operation: it is therefore better to get rid of so large a quantity of unserviceable matter, and thereby avoid also an increased expence of carriage from the calamine-furnace to the places where the brass is made. Watson's Chemical Essays, vol. iv.

Blende comprises various sulphurets of zinc, differing in the proportion of their constituent parts, and the admixture of other mineral substances.

Yellow Blende, or Phosphorescent Blende: Zinc Sulphuré Jaune, Brongniart.—The prevailing colours of this ore are yellow, passing into green, and sometimes hyacinth-red, aurora-red, or brownish-red. It occurs massive, disseminated, and crystallized. The crystals are generally small, middle-sized, and so closely aggregated, that it is difficult to determine the precise figure, which appears either the rhomboidal, the dodecahedron, the octahedron, or the tetrahedron. Yellow blende is translucent, passing into transparent, and has a splendent adamantine lustre. It yields to the knife, and affords a yellowish-grey or yellowish-white streak: it is brittle. The specific gravity rather exceeds 4: according to Karston, it is 4.1.

It decrepitates before the blow-pipe, and becomes grey; but is infusible either alone or with borax. By friction it becomes phosphorescent, and, according to Bergman, acts as powerful in this respect in water as in air.

Foliated Brown Blende: Zinc Sulphuré Brun, Brongniart.—It is of a reddish or yellowish-brown, passing into blackish-brown and dark red. It occurs massive, disseminated, and crystallized. The form of the crystals is a rhomboidal dodecahedron, either perfect or truncated on the alternate lateral angles and edges, or an octahedron, either perfect or truncated. It occurs also in tetrahedrons, perfect or truncated, and in rectangular four-sided prisms, six-sided prisms, and acicular crystals. Sometimes the crystals are joined, forming a twin crystal. The lustre is shining or splendent, and either resinous, adamantine, or semi-metallic; it has a straight lamellar structure, with a cleavage in six directions. It is more or less translucent; it yields to the knife, and affords a yellowish-grey or yellowish-brown streak; it is brittle, and easily frangible. The specific gravity of this ore varies from 3.7 to 4. It is infusible, and yields an hepatic odour when digested in sulphuric acids. The constituent parts of blende are given as under; but some varieties of foreign blende contain silex, arsenic, and manganese, which may be regarded as accidental.

Blende from Satilberg, according to Bergman:

Zinc - - - - -	44
Iron - - - - -	5
Sulphur - - - - -	17
Silex - - - - -	24
Alumine - - - -	5
Water - - - - -	5
	100

From Allonhead, in Northumberland, according to Dr. Thomson:

Zinc - - - - -	58.8
Iron - - - - -	8.4
Sulphur - - - -	23.5
Silex - - - - -	7.
	97.7

Fibrous Blende.—The colour is reddiſh-brown: it occurs reniform and maſſive. The ſtructure is divergingly fibrous in one direction, and concentric lamellar in the other: its luſtre is refinous; it is opaque or faintly tranſlucent at the edges; it agrees in other characters with foliated blende. The conſtituent parts are given as under in the Journal des Mines, t. xlix. No. 13.

Zinc	62
Iron	3
Lead	5
Arſenic	1
Sulphur	21
Alumine	2
Water	4
	98

Black Blende: Zinc Sulphuré Noir, Haüy.—It is of a greyiſh or velvet-black colour, and ſometimes browniſh-black. When tranſlucent, it appears blood-red; it is ſometimes tarniſhed with various colours. It occurs maſſive, diſſeminated, and cryſtallized, in the ſame forms as brown blende; internally it is ſhining, ſometimes ſplendent; and the luſtre is adamantine, inclining to metallic. It has a foliated ſtructure, and ſix-fold cleavage. The fragments are angular, and rather ſharp-edged. It is almoſt always opaque. The ſtreak is intermediate, between yellowiſh-grey and lightiſh-brown: it is eaſily frangible. The ſpecific gravity varies with the admixture of ingredients in this ore, from 3.9 to 4.1. Auriferous blende from Nagyag, as given by Muller, is 5.39. The conſtituent parts of black blende are as under:

Zinc	45	53
Iron	9	12
Lead	6	0
Arſenic	1	5
Sulphur	29	26
Silex	4	0
Water	6	4
	100	100

Blende is diſtinguiſhed from tin-ſtone by its inferior hardneſs; it yields pretty eaſily to the knife. It may be diſtinguiſhed from other ores which reſemble it, by the ſulphureous odour which it yields when thrown into an acid, or triturated in a mortar. The common name given to this ore by the Engliſh miners is Black Jack. It frequently occurs in the upper part of the metallic veins in Cornwall, that are rich in other ores below. Blende is not ſo valuable an ore of zinc as calamine: it muſt be freed from its ſulphur by calcination before it can be applied to the making of braſs. Some blendes loſe one-fourth of their weight, others one-ſixth by calcination. It has been for many years uſed for making braſs at Briſtol as well as calamine; but ſo little was this application of it known in other parts of the kingdom, that in the year 1777 we are informed by Dr. Watſon, in his Chemical Eſſays, that its uſe in Derbyſhire was but recently diſcovered; and he was requeſted not to divulge the purpoſe to which it might be applied, probably to evade the dues on minerals payable to the duchy court of Lancaſter.

Addenda and Corrigenda

TIN, CRYSTALLIZED, a kind of manufacture said to have been accidentally discovered in France by M. Baget, called metallic watering, or *moiré metallique*. It depends upon the action of acids, either pure or mixed together, and in different degrees of dilution, on alloys of tin. The variety of designs resembles mother-of-pearl, and reflects the light in the form of clouds. The process is this:—First, dissolve four ounces of muriate of soda in eight ounces of water, and add two ounces of nitric acid.—Second mixture; eight ounces of water, two ounces of nitric acid, and three ounces of muriatic acid.—Third mixture; eight ounces of water, two ounces of muriatic acid, and one ounce of sulphuric acid. One of these mixtures is to be poured warm upon a sheet of tinned iron, placed upon a vessel of stone-ware: it is to be poured on in separate portions, until the sheet is completely watered; it is then to be plunged into water, slightly acidulated, and washed. The watering obtained by the action of these different mixtures upon tinned iron, imitates very closely mother-of-pearl and its reflections; but the designs, although varied, are quite accidental. By heating the tinned iron to different degrees of heat, stars, fern-leaves, and other figures, are produced; and by pouring one of the above mixtures, cold, upon a plate of tinned iron, at a red heat, a beautiful granular appearance is obtained. These metallic waterings will bear the blow of a mallet, but not of a hammer; hence the invention may be used for embossed patterns, but not for those which are punched. Different colours and shades may be given by varnishes, which, when properly polished, will set off the beauty of the watering. When the tin is upon copper, the crystallization appears in the form of radiations or stars. M. Lewis Felix Vallet obtained a patent for an invention of this kind, upon delivering the following specification, Feb. 5th, 1818. The process of giving the new ornamental surface on metals or metallic compositions, consists in employing those acids and saline compounds and substances which chemically act upon tin, and which, when employed in the manner to be stated presently, give to the metals or metallic compositions to which they are applied the appearance of a crystalline surface variously modified. To produce this effect, the metal or metallic composition ought to be previously tinned, or covered with a thin coat of tin. If the metal be pure tin, it requires no previous preparation. All grease remaining on the tinned surface in consequence of tinning is to be taken off with a solution of potash, soap, or any other alkaline substances. The tin or tinned surfaces should then be washed with pure water, dried and heated to a temperature which the hand can bear. When the surface has thus been cleaned and heated, any of the acids which act upon tin, or the vapours of those acids will cause the desired appearance of crystallization; but I give the preference to the following composition, which may conveniently be laid over with a brush or a sponge. Take one part by measure of sulphuric acid, dilute it with five parts of water; take also one part of nitric acid, and dilute it with an equal bulk of water, and keep each of the mixtures separate. Then take ten parts of the sulphuric acid diluted in the manner before stated, and mix it with one part of the diluted nitric acid, and then apply this mixed acid to the tin, or to the tinned surface with a pencil or sponge, as above directed, and repeat the application of the said composition for several times successively, or until the result you expect proves satisfactory. When this has been done, the crystalline surface may be covered with a varnish or japan more or less transparent or colourless, or coloured, and lastly polished in the usual manner. Mr. Shaw, of Brunswick-square, purchased this patent, and tin-plates were made under its protection, at the manufactory of Mr. Burnell, at Battersea. But the process being generally known among chemists, the manufacture declined, and the patent, for which a considerable sum was paid, became of little value.

TIN-*Plates*. Add—The manufactory for tinning iron-plates was established at Pontypool by major John Hanbury, where he resided until his death in 1734; and the invention of the art has by some persons been erroneously ascribed to him. His monument may be seen in Trevellin church.

VOLTAISM, l. 13.—The general conclufion deduced by Galvani from his experiments was, that the animal body poffeffes an inherent electricity of a fpecific kind, which is connected with the nervous fyftem, and conveyed by means of the metals into the mufcles, fo as to throw them into convulfions. From his difcoveries he formed, with a precipitance that led him into error, a theory of mufcular motion, according to which the body contains an apparatus analogous to the Leyden phial, its different parts being in different ftates of electricity, and the metals forming a connection between them, by which the electricity is equalized. Fowler, in his "Effay on Animal Electricity," publifhed in 1793, concludes, that the galvanic influence is not referable to electricity, becaufe, for the production of the former, the prefence of two different metals appears to be neceffary, while electricity, as proceeding from the electrical machine, is excited by the action of an electric upon a conductor. He alfo endeavours to fhew, fays Dr. Boftock, the ingenious hiftorian of galvanifm, that electricity and galvanifm are not, in all cafes, conducted by the fame fubftances; and he alfo made fome curious obfervations upon the effect of galvanifm on animals not furnifhed with diftinct limbs, fuch as worms of various kinds. In the fame year, 1793, profeffor Volta's communications appeared in the Philofophical Tranfactions of London, who adds to his luminous account of Galvani's difcovery many curious experiments and obfervations of his own. He attempted, and with complete fuccefs, fays Dr. Boftock, to overthrow Galvani's opinion, that the animal body bears an analogy to the Leyden phial, its different parts being in oppofite ftates of electricity. He fuggefted, that for the production of the effect it was effential to have two different metals; and hence he was led to conclude, that the mufcular contractions are produced by fmall portions of electricity that are liberated by the action of the metals upon each other. This action of the metals upon each other is defcribed as deftroying their electrical equilibrium; and by eftablifhing a communication between them, their equilibrium is reftored. This deftruction of equilibrium he confiders as a new law of electricity difcovered by himfelf; and the animal is fuppofed to have no further concern in it, than as being a peculiarly fenfible electrometer, and affording a very delicate teft of the prefence of this difengaged electricity in its paffage from one metal to the other. He alfo eftablifhed another point, *viz.* that the nerve is the organ on which the galvanic influence immediately acts; but he found that if a part of a mufcle be laid upon two different metals, and thefe be made to communicate, a contraction is produced. He alfo confirmed the fact, previoufly noticed by Fowler, but by independent experiments, that fnails and worms could not be made to contract; but that many of the infects, as butterflies and beetles, were fubject to the influence of the metals. For an account of Dr. Wells's experiments and obfervations, we refer to his paper in the Phil. Tranf. for 1795. Profeffor Volta, profecuting his inquiry into the nature of galvanifm, was led to introduce a new principle into his theory. Having before ftated that two metals were effential to the extrication of the electric influence, he informs us, that their metallic nature may be difpenfed with, provided that the fubftances differ in their power of conducting electricity. Accordingly he divides conductors into the two claffes of dry and moift; the firft including metals and charcoal; the latter, effentially confifting of water, holding various fubftances in folution. In order to form a galvanic circuit, it is neceffary that a body from one of thefe claffes be placed between two bodies from the other clafs: and thus the equilibrium is deftroyed, which is again reftored when the two are united by a conductor. (See GALVANISM.) For further particulars we are under a neceffity of referring to Dr. Boftock's very valuable "Account of the Hiftory and prefent ftate of galvanifm," 8vo. London, 1819.

At the clofe, add—It is natural to conclude, that galvanic electricity would be applicable to medical purpofes, Accordingly we find, that about the year 1804, it was extenfively employed, more efpecially in thofe difeafes in which common electricity had been found ufeful. But the expectations that were formed concerning the efficacy of this powerful agent were generally difappointed. Flattering accounts, however, fays Dr. Boftock, (*ubi fupra*) of its fuccefs in different nervous diforders, in paralytic affections, in deafnefs, in fome kinds of blindnefs, in the recovery of perfons apparently drowned or fuffocated, and even in hydrophobia and infanity, were publifhed. But the credit of the propofed remedy was not permanent; and it therefore funk into difufe. Of late it has again been brought into notice by Dr. Philip of Worcefter, who has made trial of it, with beneficial effect, in fpafmodic afthma. Boftock's Hift.